Docket No. 10676-0057-25

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

IN RE APPLICATION OF: Fulvio ARECCO, et al. GAU:

SERIAL NO: New Application EXAMINER:

FILED: Herewith

FOR: AUTOPROTECTED OPTICAL COMMUNICATION RING NETWORK

REQUEST FOR PRIORITY

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

☐ Full benefit of the filing date of U.S. Application Serial Number, filed, is claimed pursuant to the provisions of **35 U.S.C. §120**.

■ Full benefit of the filing date of U.S. Provisional Application Serial Number 60/142,534, filed on July 7, 1999, is claimed pursuant to the provisions of **35 U.S.C. §119(e)**.

■ Applicants claim any right to priority from any earlier filed applications to which they may be entitled pursuant to the provisions of **35 U.S.C. §119**, as noted below.

In the matter of the above-identified application for patent, notice is hereby given that the applicants claim as priority:

COUNTRY	APPLICATION NUMBER	MONTH/DAY/YEAR
EUROPE	99112552.7	July 1, 1999

Certified copies of the corresponding Convention Application(s)

☐ are submitted herewith

■ will be submitted prior to payment of the Final Fee

☐ were filed in prior application Serial No. filed

☐ were submitted to the International Bureau in PCT Application Number .
Receipt of the certified copies by the International Bureau in a timely manner under PCT Rule 17.1(a) has been acknowledged as evidenced by the attached PCT/IB/304.

☐ (A) Application Serial No.(s) were filed in prior application Serial No. filed ; and

(B) Application Serial No.(s)

- ☐ are submitted herewith
- ☐ will be submitted prior to payment of the Final Fee

Respectfully Submitted,

OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT, P.C.

Charles L. Gholz
Registration No. 26,395

Phouphanomketh Ditthavong
Registration No. 44,658

22850
Tel. (703) 413-3000
Fax. (703) 413-2220
(OSMMN 10/98)

CLG:KD:brf

THIS PAGE BLANK (USPTO)

P.B.5818 - Patentlaan 2
2280 HV Rijswijk (ZH)
☏ +31 70 340 2040
TX 31651 epo nl
FAX +31 70 340 3016

Europäisches Patentamt | European Patent Office | Office européen des brevets

Generaldirektion 1 | Directorate General 1 | Direction Générale 1

A.A. THORNTON & CO.
235 HIGH HOLBORN
LONDON WC1V 7LE
GRANDE BRETAGNE

RECEIVED
12 DEC 2003
ABC.

Datum/Date
11/12/03

Zeichen/Ref./Réf.	Anmeldung Nr./Application No./Demande n°./Patent Nr./Patent No./Brevet n°.
ABC/20442	99112552.7 2415 1065822
Anmelder/Applicant/Demandeur/Patentinhaber/Proprietor/Titulaire	
PIRELLI CAVI E SISTEMI S.p.A.	

Übersendung von/Transmission of/Envoi de Antrag vom/Request dated/Requête du 03/12/03

- [ ] Kopien bei Akteneinsicht nach Regel 94(3) EPÜ
  Copies in the case of inspection of files pursuant to Rule 94(3) EPC
  Copies en cas d'inspection publique selon la règle 94(3) CBE
- [ ] Beglaubigung
  Certification
  Certification
- [X] 1 Prioritätsbeleg(e)/priority document(s)/document(s) de priorité R. 94(4)
- [ ] ___ Ausfertigung(en) der Patenturkunde nach Regel 54(2) EPÜ
  Duplicate of the patent certificate pursuant to Rule 54(2) EPC
  Duplicata du certificat de brevet, selon la Règle 54(2) CBE
- [ ] Auszug aus dem Register nach Regel 92(3) EPÜ
  Extract from the register pursuant to Rule 92(3) EPC
  Extrait du registre selon la Règle 92(3) CBE
- [ ] Auskunft aus den Akten nach Regel 95 EPÜ
  Communication of information contained in the files pursuant to Rule 95 EPC
  Communication d'informations contenues dans la dossier selon la Règle 95 CBE
- [ ] Akteneinsicht nach Regel 94(2) EPÜ
  Inspection of files pursuant to Rule 94(2) EPC
  Inspection publique selon la Règle 94(2) CBE

VAN DER AA-JANSEN C G (TEL:2289)

Europäisches
Patentamt

European
Patent Office

Office européen
des brevets

Bescheinigung

Certificate

Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

99112552.7

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

R C van Dijk

DEN HAAG, DEN
THE HAGUE, 11/12/03
LA HAYE, LE

Europäisches Patentamt | European Patent Office | Office européen des brevets

Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr.:
Application no.: 99112552.7
Demande n°:

Anmeldetag:
Date of filing: 01/07/99
Date de dépôt:

Anmelder:
Applicant(s):
Demandeur(s):
PIRELLI CAVI E SISTEMI S.p.A.
20126 Milano
ITALY

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:
Autoprotected optical communication ring network

In Anspruch genommene Prioriät(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

Staat: State: Pays:	Tag: Date: Date:	Aktenzeichen: File no. Numéro de dépôt:

Internationale Patentklassifikation:
International Patent classification:
Classification internationale des brevets:
H04J14/02

Am Anmeldetag benannte Vertragstaaten:
Contracting states designated at date of filing: AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE
Etats contractants désignés lors du depôt:

Bemerkungen:
Remarks:
Remarques:

European Patent Application No. 97123013.1-2209 filed on 31/12/97 in the name of the Applicant relates to a method and an apparatus for transparent optical communication with two-fiber bidirectional ring with autoprotection and management of low priority traffic. The communication network comprises two optical fibers (an external one and an internal one) that interconnect the nodes. According to the proposed technique, if a first and a second node of the network are considered for mutual signal transmission, a high-priority traffic can be set up on a first bidirectional communication path defined between the two nodes on the external and internal fibers, using only an arc of the communication ring defined between the two nodes. The arc complementary to that just described can be used as a second bidirectional communication path between the two nodes for low-priority traffic, using the same wavelength as the preceding channel. The protection mechanism consists of redirecting the high-priority traffic onto the second path in the case of a breakdown in, or degradation of, communication on the first path, thus losing the low-priority traffic on the second path. This protection method is identifiable as a "Optical Channel 1:1 Dedicated Ring Protection" method with management of Low-Priority traffic. The Applicant observes that, although this method provides a double capacity with respect to the previous technique, with N wavelengths it is still not possible to protect more than N channels.

The article "A Transparent, All-Optical, Metropolitan Network Experiment in a Field Environment: The "PROMETEO" Self-Healing Ring", F. Arecco et al., IEEE Journal of Lightwave Technology, Vol.5, Dec 1997, describes a method to provide protection against failures in a metropolitan ring network. According to this method, a working fiber ring is used to carry all the optical channels between nodes, while a protection fiber ring is empty under normal operating conditions. In case of failure, a protection switching takes place at the nodes adjacent to the failure, which reconfigure in such a way to route all the optical channels (i.e. all the wavelengths of the multiplex section) through the protection fiber ring so as to bypass the failure. This protection method is known as "Optical Multiplex Section Protection" method. The Applicant observes that, once more, with N wavelengths it is possible to carry only N protected channels. Moreover, the Applicant further observes that, in this case, it is not possible to have different protection mechanisms (i.e protection at different layers) for different channels, and that the optical path after a protection reconfiguration can be longer than the ring circumference.

U.S. Patent No. 5,647,035 in the name of CSELT - Centro Studi e Laboratori Telecomunicazioni S.p.A. - provides a ring network communication structure on an

AUTOPROTECTED OPTICAL COMMUNICATION RING NETWORK

The present invention relates to an autoprotected optical communication ring network, in particular a WDM (Wavelength Division Multiplexing) autoprotected optical communication ring network of the type including a plurality of nodes connected to each other in pairs by means of respective optical connections susceptible to failure, each connection comprising at least a first and a second optical carrier having opposite transmission directions.

"Optical communication ring network" here means not only a communication network configured as a whole as a ring but, in general, any section of a network comprising a plurality of nodes and branches and arranged, at least temporarily, in a ring configuration.

Specifically, the present invention tackles the problem of making a ring network with self-healing capabilities, i.e. capabilities of managing failures which may arise in the connections between the network nodes.

"Failure" here means any event which may affect the physical optical carriers (e.g. breakage or interruption of an optical fiber) and/or the devices of the network operating on the transmitted signals (e.g. receivers, demultiplexers, amplifiers, etc.), in such a way as to bring about a situation of degradation of the transmission which is deemed not tolerable; the term "failure" thus should in no way be interpreted as being limited only to events causing the complete interruption of the connection.

The state of the art includes many methods to optically protect a set of wavelength multiplexed optical channels carried by a two-fiber optical ring network.

European Patent Application No. 769859 in the name of the Applicant relates to a transparent optical self-healing-ring communication network in which at least two nodes are optically connected along a first and a second closed optical path having opposite transmission directions. Each node simultaneously feeds its transmitted signals to the first and the second closed optical path, so that the signals travel along complementary arcs of the ring. The receiving node selectively receives the signals from one of the two closed paths and, in case of failure on this closed path, switches reception on the other closed path. The Applicant observes that this Optical Channel Protection method, identifiable as a "Optical Channel 1+1 Dedicated Ring Protection" method, requires that, for each wavelength used on one closed path, the same wavelength cannot be used on the other closed path other than for protection. Thus, with N wavelengths, only N protected channels can be used in the network.

optical carrier and a reconfigurable node for said structure. In said structure, a plurality of nodes are interconnected by means of connections comprising at least a first and a second optical carrier, such as an optical fiber. Transmission between two nodes occurs on the ring according to a WDM scheme, by utilizing a first wavelength for communication in one direction on the first carrier and a second wavelength for communication in the opposite direction on the second carrier. The second wavelength on the first carrier and the first wavelength on the second carrier are reserved for protection (protection channels) and are "shared" among all the nodes. Under regular operation conditions of the network, in each node the signals conveyed by the two fibers are detected, processed as required in units of a higher hierarchical level, converted again in optical signals and re-transmitted towards the following node. In the presence of a failure on one of the connections, the nodes adjacent to the failed connection reconfigure themselves to ensure the continuation of communication on the alternative path provided by the ring, by utilizing the first wavelength on the second carrier and the second wavelength on the first carrier. The exemplary embodiment described referring to just two wavelengths λ_1, λ_2, can be generalized to any number of wavelengths with a corresponding expansion of the described connection; switching matrices of the nxn type may be used.

The Applicant noticed that, in the ring network proposed in US 5,647,035, if multi-wavelength signals have to be managed, since signal re-routing is localized at the nodes adjacent to the failure, the protection operations have to be performed on the entire set of wavelengths of the multiplex section (as described for SDH in ITU-T Recommendation G-803 and G-841) and the reconfigured nodes must re-route all the working channels previously sent on the damaged ring segment to their respective protection channels running onto the complementary ring arc. This technique is then identifiable as an "Optical Multiplex Section Shared Protection" technique. Thence, each node in the network must be equipped with the optical switching tools for the complete set of wavelengths in the ring, and a switch matrix is then needed with a complexity which increases considerably with increasing the number of channels (e.g. if each channel carries 2.5 Gb/s and the system is adapted to transmit 16 channels, each matrix must be able to switch 16 x 2.5 Gb/s). It can be demonstrated that, in this case, the required optical switching blocks to protect a number of links between N and MN/2 (where N is the number of wavelengths and M the number of nodes) is always MN.

Furthermore, the Applicant observes that, in the Optical Multiplex Section Shared Protection, since the failure control is performed at the multiplex section

level, a failure on a single optical channel (e.g. when a node transmitter is damaged) can be either ignored or it can cause the reconfiguration of all the traffic thus causing a temporary failure on all the other working channels.

The Applicant further observes that, in case such a network is reconfigured as a consequence of a failure, the protection path of a generic optical channel may be longer than the maximum ring circumference. This can occur when a generic bidirectional link is set up between two non-adjacent nodes in the network, as illustrated in Figure 1a (where nodes A and D are involved). In case of failure the switching action is performed by the two nodes adjacent to the failure (i.e. nodes B and C), as shown in Figure 1b. Briefly, each channel of the bidirectional link travels along the working path from the source node to one of the reconfigured nodes where it is routed into the protection path. Then it travels in opposite direction along all the ring network to the other reconfigured node where it is routed again on the working path and, finally, it reaches the destination node. This alternative optical channel path may have a length exceeding the ring circumference, reaching values of several hundred chilometers and then introducing low levels of S/N ratio and high levels of attenuation. In case of a transoceanic application, this protection solution may lead, due to loopbacks, to restoration transmission paths that would cross the ocean three times.

To overcome this last problem, a different protection solution has been proposed, which is referred to as a "MS shared protection ring - transoceanic application" in the Annex A of the Telecommunication standard ITU-T Recommendation G.841. In brief, a failure is detected at the two nodes adjacent to the failure at the SDH multiplex section layer and, subsequently, the nodes terminating failured links are informed of the failure situation and re-route the corresponding links on the complementary ring arc path, as illustrated in Figure 1c. In other words, in case of failure, all the transmission links affected by the failure are bridged at their source nodes onto the protection channels that travels away from the failure. When the affected links reach their final destination nodes, they are switched to their original drop point. Therefore, no loopbacks are established and there is no risk of having, in case of failure, restoration transmission paths crossing more times the ocean.

The Applicant observed that, in this case, as in the protection solution of U.S. Patent No. 5,647,035, the failure control is over the entire optical multiplex section and, therefore, a failure on a single optical channel may be either ignored or it can

cause the reconfiguration of all the traffic thus causing a temporary failure on all the other working channels.

The Applicant further observes that a protection at the SDH layer requires a relatively complex electronic layout and can operate only at a predetermined bit rate.

The Applicant proposes, with the present invention, an improved type of shared protection technique, in which re-routing operations are performed only at the nodes which terminate affected links and only on the failured channels, thus avoiding the drawbacks related to re-routing operations on the multiplex section, and by using an optical reconfigurable connection mechanism which allows the omission of a SDH layer protection mechanism. Moreover, the failure control is performed at the channel level instead of at the multiplex section level, thus avoiding the above mentioned drawbacks.

In the proposed network, the nodes communicate in pairs defining bidirectional links, and, under normal conditions, are optically configured so as to exchange signals on a respective working arc path at a respective first wavelength on a first carrier of the network and at a respective second wavelength on a second carrier of the network; in the complementary arc, the same wavelengths may be used in the same manner to define other links, while the first wavelength on the second carrier and the second wavelength on the first carrier are reserved for protection and are used in case of failure affecting one of said links. Each node of the proposed network is provided with a pair of OADM (Optical Add/Drop Multiplexers) for extracting from, and inserting in, the optical multiplex section, only the channels which the node is adapted to operate on. All the remaining channels are passed-through. Each node is further provided with a receiving/transmitting module for each pair of wavelengths defining a transmission link, said module optically connecting, in a selective way, the OADMs to optical transmitters and receivers operating at said wavelengths. Each receiving/transmitting module performs failure control and re-routing operations on the two corresponding wavelengths. Consequently, in case of failure, if one of the links managed by this node is failed, the corresponding receiving/transmitting module, after detecting the failure by checking the channels status, is reconfigured in order to optically re-route the transmission on the complementary portion of the ring. The same operation is performed by the node at the other end of the failed link. Therefore, only the nodes managing affected links are optically reconfigured and only the failured channels (instead of the global multiplex section) are re-routed.

The protection technique of the invention provides the following advantages:

- By operating protection at the channel level, it is possible to provide optical

protection to a selected subset of optical channels and leave to other layers (e.g. SDH) or to other optical protection mechanisms the protection of the remaining channels.

- Using an optical re-routing technique, it is possible to omit the SDH protection layer, thus simplifying the node structure and allowing a direct connection to the ring network for clients using different protocols (possibly unprotected) like ATM, IP, etc. The proposed protection technique is therefore compatible with every client electronic transmission protocol.

- The receiving/transmitting module in the protection scheme of the invention includes an optical switching unit which, differently from SDH switching layouts, can operate at different bit rates (for example 155 Mbit/s, 622 Mbit/s, 2,5 Gbit/s, 10 Gbit/s)

- The protection technique of the invention allows a client to client protection, since a failure is detectable even if it affects a single channel, while generally the prior art techniques allow only global failure detection on the multiplexed flux (by using threshold photodiodes).

- The number of switching blocks is always two times the number of protected channels (i.e. between 2N and MN, where N is the number of wavelengths and M the number of nodes) thus giving an advantage, with mixed traffic patterns, over the Optical Multiplex Section Shared Protection schema proposed in US 5,647,035. For example, with a typical 8 nodes, 32 wavelengths optical ring network (M=8, N=32), the required number of switching blocks for said Optical Multiplex Section Shared Protection schema is always 256, while by using the Optical Channel Shared Protection schema of the invention the required number of switching blocks varies between 64 (in case of "hub traffic", i.e. one node communicating with all the other nodes) and 256 (in case of "uniform traffic", i.e. one node communicating only with its two adjacent nodes).

- Since the reconfiguration takes place at the channel level instead of at the multiplex section level as in US 5,647,035, it is no more needed to provide each node with a switching equipment to perform protection on all the network channels (in particular it is then not necessary to use complex switch matrix as in the Optical Multiplex Section Shared Protection scheme).

- Differently from the Optical Multiplex Section Shared Protection scheme proposed in US 5,647,035, the complexity of the node switching structure depends only on the number of links managed by the nodes and does not depend on the number of wavelengths in the network.

- Differently from the Optical Multiplex Section Shared Protection scheme proposed in US 5,647,035, switching operations are performed externally to the network, and then no transitories are present. In particular, switching of the single channel is performed, as described below, between the receiving and the transmitting transponders and, therefore, the multiplexed optical flux conditions at the input of the node amplifier are substantially unchanged and then sudden power variations inside the network are avoided.

According to a first aspect, the present invention relates to an autoprotected optical communication ring network, including a first and a second optical carrier having opposite transmission directions and a plurality of optically reconfigurable nodes optically connected along the first and the second optical carrier and adapted to communicate in pairs by means of respective links susceptible of failure, the ring network having a normal operative condition in which the nodes of each pair are optically configured so as to exchange optical signals on a respective working arc path at a respective first wavelength on the first carrier and at a respective second wavelength different from said first wavelength on the second carrier, said respective working path having a complementary arc path defining a respective protection arc path in which the first wavelength on the first carrier and the second wavelength on the second carrier can be used for further links and the first wavelength on the second carrier and the second wavelength on the first carrier are reserved for protection, characterized in that the ring network has a failure operative condition in which the nodes terminating a failured link are optically reconfigured so as to exchange optical signals on the respective protection arc path at the respective second wavelength on the first carrier and at the respective first wavelength on the second carrier.

Preferably, each of said plurality of reconfigurable nodes is adapted to manage a predetermined subset of wavelengths within a set of transmission wavelengths and includes a first and a second optical add/drop multiplexer serially connected to said first and, respectively, second carrier to feed/extract said subset of wavelengths to/from said first and, respectively, second carrier, and to pass-through the remaining wavelengths of the set of transmission wavelengths.

Each of said plurality of reconfigurable nodes preferably includes at least an optical transmitter, at least an optical receiver and a reconfigurable optical switch unit selectively coupling said optical transmitter and said receiver to said first and second carriers.

Each of said plurality of reconfigurable nodes may include information

insertion devices selectively optically connectable to said at least an optical transmitter and adapted to insert signalling information into the optical signals and information extraction devices selectively optically connectable to said at least an optical receiver and adapted to extract signalling information from the optical signals.

Said information insertion devices and said information extraction devices may include optical transponders optically coupling said optical switch unit to said first and second carrier and adapted to change the signals wavelengths.

According to a second aspect, the present invention relates to a method to autoprotect an optical ring network, said ring network including a first and a second optical carrier having opposite transmission directions and a plurality of nodes optically connected along the first and the second optical carrier and adapted to communicate in pairs in order to define bidirectional links, each pair including a first and a second link termination node adapted to mutually communicate at respective first and second wavelengths, the method including:

- exchanging signals between the first and the second link termination node of each pair on a respective working arc path of said ring network by using the respective first wavelength on the first carrier and the respective second wavelength on the second carrier; said respective working path having a complementary arc path defining a respective protection arc path in which the first wavelength on the first carrier and the second wavelength on the second carrier can be used for further links and the first wavelength on the second carrier and the second wavelength on the first carrier are reserved for protection;
- checking if a failure is present in the ring network producing at least a failured link; and
- optically reconfiguring, in the presence of a failure, the link terminating nodes of said at least a failured link so that they exchange signals on the respective protection arc path by using the respective first wavelength on the second carrier and the respective first wavelength on the second carrier.

Preferably, each node of said plurality of nodes is adapted to manage a predetermined subset of wavelengths within a set of transmission wavelengths carried by the first and the second carrier, said step of exchanging including optically separating, at each node of said plurality of nodes, each wavelength of the respective subset of wavelengths from the set of transmission wavelengths.

The step of checking may include verifying, in each node of said plurality of nodes and for each wavelength of the respective set of wavelengths, if signals are received.

The step of checking may include verifying, in each node of said plurality of nodes and for each wavelength of the respective set of wavelengths, if signals are received degraded.

The step of checking may include verifying, in each node of said plurality of nodes and for each wavelength of the respective set of wavelengths, if signals include a failure message.

The method may further include transmitting a failure message from a first link termination node of a pair to a second link termination node of the same pair if a signal transmitted from the second link termination node to the first link termination node is not received, or is received degraded, by the first link termination node.

Advantageously, the step of reconfiguring includes switching optical connections which selectively couple at least an optical transmitter and an optical receiver to said first and second carrier.

Preferably, the step of exchanging includes feeding at each of said plurality of nodes the corresponding subset of wavelengths to said first and, respectively, second carrier.

The step of exchanging signals may include the following steps executed in the first link termination node of a pair:

- generating an optical signal carrying an information;
- converting the optical signal in a electrical signal;
- adding to the electrical signal further information;
- reconverting the electrical signal in an optical signal provided with a predetermined wavelength adapted for transmission; and
- feeding the optical signal at the predetermined wavelength to either the first or the second carrier;

and the following steps executed in the second link termination node of the same pair:

- receiving the optical signal at the predetermined wavelength from either the first or the second carrier;
- converting the optical signal at the predetermined wavelength in an electrical signal;
- extracting from the electrical signal the further information;
- reconverting the electrical signal in an optical signal with a wavelength adapted for reception; and
- receiving the optical signal with the wavelength adapted for reception.

According to a further aspect, the present invention relates to a

reconfigurable node for an autoprotected optical communication ring network, comprising a receiving/transmitting module including:

- an optical transmitter to generate a signal including information to be transmitted in the network;
- an optical receiver to receive a signal including information transmitted in the network;
- a first transmitting transponder for optically coupling to a first carrier of the network and adapted to modulate a signal at a first wavelength;
- a second transmitting transponder for optically coupling to the first carrier and adapted to modulate a signal at a second wavelength;
- a third transmitting transponder for optically coupling to a second carrier of the network and adapted to modulate a signal at the first wavelength;
- a first receiving transponder for optically coupling to the first carrier and adapted to demodulate a signal having the first wavelength;
- a second receiving transponder for optically coupling to the first carrier and adapted to demodulate a signal having the second wavelength;
- a third receiving transponder for optically coupling to the second carrier and adapted to demodulate a signal having the second wavelength;
- reconfigurable optical connections to selectively connect:
    - the optical transmitter either to the first transmitting transponder or to the third transmitting transponder;
    - the first receiving transponder to the third transmitting transponder;
    - the second receiving transponder to the optical receiver; and
    - the third receiving transponder either to the optical receiver or to the second transmitting transponder.

The receiving/transmitting module may further include:

- a further optical transmitter to generate a signal including information to be transmitted in the network;
- a further optical receiver to receive a signal including information transmitted in the network;
- a fourth transmitting transponder optically coupled to the second carrier and adapted to modulate a signal at the second wavelength; and
- a fourth receiving transponder optically coupled to the first carrier and adapted to demodulate a signal having the first wavelength;

said reconfigurable optical connections selectively connecting:

- the first receiving transponder either to the third transmitting transponder or

to the further receiver;

- the fourth receiving transponder to the further receiver; and
- the further optical transmitter either to the second transmitting transponder or to the fourth transmitting transponder.

Preferably, the node is adapted to manage a predetermined set of wavelengths within a set of transmission wavelengths including a first and a second optical add/drop multiplexer optically coupling the receiving/transmitting module to said first and, respectively, second carrier to feed/extract said subset of wavelengths to/from said first and, respectively, second carrier, and to pass-through the remaining wavelengths of the set of transmission wavelengths.

The reconfigurable optical connections may include 2x2 switches or, alternatively, 1x2 and 2x1 switches.

The reconfigurable optical connections may include discrete switching components or, alternatively, an integrated switching matrix.

The reconfigurable optical connections may include optical switching components selectable in the group including:

- opto-mechanical switches;
- thermo-optical switches;
- magneto-optical switches;
- liquid crystal switches;
- semiconductor switches;
- electro-optical switches;
- micro-mechanical switches; and
- lithium niobate integrated circuit switches

The reconfigurable node preferably includes a control processing unit operatively connected to said receiving transponders and said transmitting transponders.

The reconfigurable node may includes at least a further receiving/transmitting module which has substantially the same structure of said receiving/transmitting module and is adapted to operate with a different pair of wavelengths with respect to said receiving/transmitting module.

More details will become apparent from the following description, with reference to the accompanying drawings, in which:

Figures 1a, 1b, 1c show a network ring of a known type under normal condition, failure condition with a multiplex section shared protection and failure condition with a multiplex section shared protection – transoceanic application.

Figure 2 is a schematic representation of an optical communication network according to the present invention, operating under normal conditions and in which, by way of example, two transmission links are defined;

Figure 3 is a more detailed representation of one node of the network of Figure 2, including a switching unit comprising 2x2 switches and operating under normal conditions;

Figure 4 shows a switching unit comprising 1x2 and 2x1 switches used in the network of Figure 2 in place of the switching unit comprising 2x2 switches, operating under normal conditions;

Figure 5 shows a switching unit comprising an integrated switching circuit used in the network of Figure 2 in place of the switching unit comprising 2x2 switches, operating under normal conditions;

Figure 6 illustrates a sub-equipped node for the network of Figure 2, adapted to manage only one transmission link and including 2x2 switches;

Figure 7 shows a switching unit comprising 1x2 and 2x1 switches used in the network of Figure 6 in place of the switching unit comprising 2x2 switches, under normal operative conditions;

Figure 8 shows a switching unit comprising an integrated switching circuit used in the network of Figure 6 in place of the switching unit comprising 2x2 switches, under normal operative conditions;

Figure 9 illustrates the network of Figure 2 under a failure condition;

Figure 10 shows the reconfiguration of the node of Figure 3 when a failure occurs on its left-hand side;

Figure 11 shows the reconfiguration of the switching unit of Figure 4 when a failure occurs on the left-hand side of the node;

Figure 12 shows the reconfiguration of the switching unit of Figure 5 when a failure occurs on the left-hand side of the node;

Figure 13 shows the reconfiguration of the node of Figure 3 when a failure occurs on its right-hand side;

Figure 14 shows the reconfiguration of the switching unit of Figure 4 when a failure occurs on the right-hand side of the node; and

Figure 15 shows the reconfiguration of the switching unit of Figure 5 when a failure occurs on the right-hand side of the node.

Schematically shown in Figure 2 is an optical communication ring network 1 according to the present invention. Network 1 includes a first and a second optical fibre ring 2, 3 defining respective optical carriers having opposite transmission

directions, and a plurality of nodes 20a-20f for adding and dropping optical signals, positioned along the first and the second ring 2, 3.

Network 1 is adapted to be used for both terrestrial transmissions and transoceanic transmissions. For long-haul transmissions, in particular for transoceanic transmissions, network 1 is preferably provided with line optical amplifiers and/or boosters and/or preamplifiers (not shown).

In the schematic representation of Figure 2, rings 2, 3 define an external and, respectively, an internal ring, having a counter-clockwise transmission direction and, respectively, a clockwise transmission direction. The nodes in network 1 have been chosen in number of six just by way of example and the present invention is identically applicable to networks including any number of nodes. Furthermore, the reference to connections comprising two optical fibers is to be considered merely as an example, the solution according to the invention being also suitable for utilization in ring networks in which the nodes are connected by a greater number of optical carriers.

Communication in network 1 is achieved according to a Wavelength Division Multiplexing (WDM) scheme using different channels at respective wavelengths on each ring. In particular, rings 2, 3 are adapted to convey optical signals in the transmission channels defined by a set of transmission wavelengths λ_1, λ_2, .., λ_N within a predetermined wavelength transmission band.

Each of the nodes 20a-20f is adapted to manage a respective subset of wavelengths within the set of transmission wavelengths λ_1, λ_2, .., λ_N and to define bidirectional communications with one or more of the other nodes of network 1. Each pair of nodes arranged to mutually communicate splits network 1 into two complementary arc paths, at least one of which (identifiable as a "working path") allows bidirectional transmission between the two nodes under normal operative conditions (i.e. without failures), and the other (identifiable as a "protection path") allows to re-route such bidirectional transmission in the presence of a failure in the working path.

In greater detail, a generic pair of nodes arranged to mutually communicate has associated respective first and second wavelengths λ_x, λ_y for the exchange of data. Under normal operative conditions, on the working path defined by the considered pair of nodes, a bi-directional working link is established by transmitting optical signals at the first wavelength λ_x on the external ring 2 (in the counter-clockwise direction) and at the second wavelength λ_y on the internal ring 3 (in the clockwise direction). The second wavelength λ_y is not used on the external ring 2 and

the first wavelength λ_x is not used on the internal ring 3. The second wavelength λ_y and the first wavelength λ_x can then be used on the external ring 2 and, respectively, on the internal ring 3, to provide optical protection, as hereinbelow described. For aim of clarity, the wavelengths which are used under normal operative conditions (i.e. λ_x on the esternal ring 2 and λ_y on the internal ring 3) to perform working links are identified with a "w" suffix ($\lambda_{x,w}$, $\lambda_{y,w}$), while the wavelengths which are adapted to be used for protection (i.e. λ_y on the esternal ring 2 and λ_x on the internal ring 3) are identified with a "p" suffix ($\lambda_{x,p}$, $\lambda_{y,p}$).

The first and the second wavelength λ_x, λ_y can be used on the protection path associated to the considered pair of nodes to perform a further bidirectional working link between the first and the second node or to perform further bidirectional working links between other pairs of nodes (which may include one of the previously considered nodes), provided that those further working links do not overlap with each other and with the above considered one. Then, a generic pair of wavelengths λ_x, λ_y defines a "logical ring", i.e. a virtual ring which may include many non-overlapping working links operating at $\lambda_{x,w}$, $\lambda_{y,w}$. Protection wavelengths $\lambda_{x,p}$, $\lambda_{y,p}$, not used under normal operative conditions, are shared among the different working links operating at $\lambda_{x,w}$, $\lambda_{y,w}$ (i.e. on the same logical ring). Overlapping working links can only be part of different logical rings and operate at different wavelengths.

The number of working links in a single logic ring depends on the client traffic pattern. For example with M nodes and N wavelengths (N even), in case of "hub traffic" (i.e. one node communicating with all the other nodes) a maximum of N protected working links can be established because each logical ring can support only two working links, while in case of "uniform traffic" (i.e. each node communicating only with its two adjacent) a maximum of MN/2 protected working links are available because each logical ring (i.e. each pair of wavelengths) can support M working links.

In the example of Figure 2, one working link is set up between node 20c and node 20f using the first working wavelength $\lambda_{x,w}$ on the external ring 2 and the second working wavelength $\lambda_{y,w}$ on the internal ring 3. Another working link is set up with the same wavelengths (and directions of propagation on the two rings 2, 3) between node 20d and node 20e. In this example, it is also possible to use the same wavelengths to set up a working link between node 20c and node 20d and between node 20e and node 20f, but it is not possible for example to set up a working link between node 20b and node 20e because it will overlap with the ring arcs already used by the previous links.

As later described in greater detail, each of nodes 20a-20f provides optical add/drop/bypass functions for each wavelength within the wavelength transmission band on both the external and internal fiber rings 2, 3, together with optical amplification and regeneration (if necessary).

Figure 3 shows the structure of a generic node 20i of network 1, in particular of one node operating at wavelengths λ_x and λ_y.

Node 20i includes a first and a second optical add/drop multiplexer (OADM) 4, 5 and a receiving/transmitting module 6 comprising:

- a first and a second transmitter Tx_1, Tx_2;
- a first and a second receiver Rx_1, Rx_2;
- a first, a second, a third and a fourth transmitting transponder $TxT_1(\lambda_x)$, $TxT_1(\lambda_y)$, $TxT_2(\lambda_x)$, $TxT_2(\lambda_y)$;
- a first, a second, a third and a fourth receiving transponder $RxT_1(\lambda_x)$, $RxT_1(\lambda_y)$, $RxT_2(\lambda_x)$, $RxT_2(\lambda_y)$;
- a switch unit 15; and
- a central processing unit (CPU) 16.

The first and the second OADM 4, 5 are adapted to insert into rings 2, 3, and to extract from rings 2, 3, signals at the working and protection wavelengths associated to node 20i (i.e. λ_x and λ_y) and to by-pass the other wavelengths of the set of transmission wavelengths. If required, OADMs 4, 5 may perform other functions within the wavelength transmission band, such as regeneration, performance monitoring, etc. In greater detail, the first OADM 4 is coupled to the fiber of the external ring 2 for dropping signals from, and adding signals into, the external ring 2, and the second OADM 5 is coupled to the fiber of the internal ring 3 for dropping signals from, and adding signals into, the internal ring 3. OADMs 4 and 5 may be, for example, of the type Pirelli Optical Systems OADM/P4-R1 (WaveMux6400 product family).

Transmitters Tx_1, Tx_2 and receivers Rx_1, Rx_2 represent the client access points for the input and the output of information. In particular, transmitters Tx_1, Tx_2 allows the input of information addressed to two different receivers connected to network 1. The input of information by transmitters Tx_1, Tx_2 may be performed at wavelengths not included in the transmission wavelength band of network 1, since the transmitting transponders TxTs are in charge to provide the signals with the correct wavelength, i.e. with the first wavelength λ_x or the second wavelength λ_y. Tx_1, Tx_2 may be, for example, for example a standard Sonet OC-48/SDH STM-16 terminal (produced for example by Nortel). Different bit rate terminals can be used provided that the

transmitting transponders are compatible.

Receivers Rx_1, Rx_2 allow the output of information coming from two different transmitters connected to network 1. Receivers Rx_1, Rx_2 may be adapted to receive signals at wavelengths not included in the transmission wavelength band of network 1, since receiving transponders RxTs are in charge to provide the signals coming from the network 1 with a wavelength adapted for reception receivers Rx_1, Rx_2. Rx_1, Rx_2 may be, for example, a standard Sonet OC-48/SDH STM-16 terminal (produced for example by Nortel). Different bit rate terminals can be used provided that the receiving transponders are compatible.

The first and the second transmitting transponder $TxT_1(\lambda_x)$, $TxT_1(\lambda_y)$ are optically coupled to the external ring 2 by means of the first OADM 4 and are adapted to feed signals at wavelength λ_x and, respectively, λ_y, to the external ring 2; the third and the fourth transmitting transponder $TxT_2(\lambda_x)$, $TxT_2(\lambda_y)$ are optically coupled to the internal ring 3 by means of the second OADM 5 and are adapted to feed signals at wavelength λ_x and, respectively, λ_y, to the internal ring 3.

In detail, each transmitting transponder $TxT_1(\lambda_x)$, $TxT_1(\lambda_y)$, $TxT_2(\lambda_x)$, $TxT_2(\lambda_y)$ may be of a type adapted to receive an optical signal from switch unit 15, to transform it into electrical format for processing and to newly transform it into optical format for transmission, with a predetermined wavelength within the wavelength band. Transmitting transponders of this type are, for example, Pirelli Optical Systems WCM/F-xxx (WaveMux6400 product family, xxx = output wavelength code). Alternatively, the transmitting transponder may be completely optical devices (for example based on SOAs, Semiconductor Optical Amplifiers) managing information associated to the signal, for example managing a pilot tone over-modulating the optical wavelength carrying the signal.

Processing, in this case, includes providing the transmitted signals with information for protection purposes (e.g. channel identifier, performance monitoring, protection protocol) as a channel overhead. This information is not part of the client payload and are added to the signal by the transmitting transponders under the supervision of the CPU. For example the Pirelli Optical Systems WCM/F-xxx unit is able to add an overhead channel to the client payload to transport the signalling information. A similar technique, but operating at the multiplex section level, is used in the Sonet/SDH protocol at the transmitting side (e.g. channel overhead, multiplex section overhead with B1 monitor byte and K1/K2 APS bytes).

The first and the second receiving transponder $RxT_1(\lambda_x)$, $RxT_1(\lambda_y)$ are optically coupled to the external ring 2 by means of the first OADM 4 and are adapted to

receive signals at wavelength λ_x and, respectively, λ_y; the third and the fourth receiving transponder $RxT_2(\lambda_x)$, $RxT_2(\lambda_y)$ are optically coupled to the internal ring 3 by means of the second OADM 5 and are adapted to receive signals at wavelength λ_x and, respectively, λ_y.

In detail, each receiving transponder $RxT_1(\lambda_x)$, $RxT_1(\lambda_y)$, $RxT_2(\lambda_x)$, $RxT_2(\lambda_y)$ may be of the type adapted to receive an optical signal from rings 2, 3, to transform it into electrical format for processing and to newly transform it into optical format, with a predetermined wavelength adapted for reception by a corresponding receiver Rx_1, Rx_2. Receiving transponders of this type are, for example, Pirelli Optical Systems RXT-DM/F (WaveMux6400 product family). Alternatively, the receiving transponders, like the transmitting transponders, may be completely optical devices (for example based on SOAs, Semiconductor Optical Amplifiers) managing information associated to the signal, for example to a pilot tone over-modulating the optical wavelength carrying the signal.

Processing, in this case, includes extracting from the received signals the information previously inserted as channel overhead by the corresponding TXT at the transmitting node for protection purposes (e.g. channel identifier, performance monitoring, protection protocol). For example the Pirelli Optical Systems RXT-DM/F unit is able to extract an overhead channel from the received signal to process the signalling information. A similar technique, but operating at the multiplex section level, is used in the Sonet/SDH protocol at the receiving side (e.g. channel overhead, multiplex section overhead with B1 monitor byte and K1/K2 APS bytes).

CPU 16 is in charge to communicate with the transmitting and receiving transponders TxTs, RxTs in order to provide or to process the information related to the working links (link signalling), to check the operative conditions of the related working links and to control switch unit 15 in accordance to the detected operative conditions. Link signalling must include channel identification information which can be implemented for example either by means of a pilot tone over-modulating the optical wavelength carrying the signal or by using a TDM (Time Division Multiplexing) frame structure including the signal channels together with an extra channel for link signalling transmission. Logical connections between CPU 16 and its controlled units are represented in Figure 3 by means of dashed lines.

Switch unit 15 is adapted to provide the optical switching facilities implementing the protection layout as disclosed in this invention, by selectively connecting transmitters Txs and receivers Rxs to transmitting transponders TxTs and receiving transponders RxTs. As shown in Figure 3, switch unit 15 may comprise a first, a

second, a third and a fourth 2x2 optical switch 22-25 driven by CPU 16 through appropriate control logics (not shown). Optical switches 22-25 may be, for example, 2x2 optomechanical switches (e.g. of the type produced by JDS FITEL, INC., 570 Heston Drive, Nepean, Ontario (CA) or of the type produced by E-TEK DYNAMICS, INC., 1885 Lundy Ave., San Jose, CA (USA)). Optical switches 22-25 are connected as follows:

- the first switch 22 has a first input 22a coupled to the first transmitter Tx_1, a second input 22b, a first output 22c coupled to the first transmitting transponder $TxT_1(\lambda_x)$ and a second output 22d coupled to the third transmitting transponder $TxT_2(\lambda_x)$;
- the second switch 23 has a first input 23a coupled to the fourth receiving transponder $RxT_2(\lambda_y)$, a second input 23b coupled to the second receiving transponder $RxT_1(\lambda_y)$, a first output 23c coupled to the first receiver Rx_1 and a second output 23d;
- the third switch 24 has a first input 24a coupled to the second output 23d of the second switch 23, a second input 24b coupled to the second transmitter Tx_2, a first output 24c coupled to the second transmitting transponder $TxT_1(\lambda_y)$ and a second output 24d coupled to the fourth transmitting transponder $TxT_2(\lambda_y)$; and
- the fourth switch 25 has a first input 25a coupled to the third receiving transponder $RxT_2(\lambda_x)$, a second input 25b coupled to the first receiving transponder $RxT_1(\lambda_x)$, a first output 25c coupled to the second input 22b of the first switch 22 and a second output 25d coupled to the second receiver Rx_2.

Each switch 22-25 can operate in a bypass status (typically used under normal conditions), in which the first input is coupled to the first output and the second input is coupled to the second output, or in a switched status (typically used in case of failure), in which the first input is coupled to the second output and the second input is coupled to the first output.

The architecture of Figure 3 is modular and can be applied for each logical ring in which the node acts as a link termination. In other words, node 20i may include a plurality of modules 6, each for managing a different pair of wavelength. In this case, the wavelengths assigned to each logical ring are separately added/dropped by the two OADMs 4, 5 and processed separately by a corresponding module 6.

It has to be noted that the functional layout of the node described above can be physically implemented in different ways, for example integrating the CPU 16 or the transponders 6-13 inside the switch unit 15.

Swich unit 15 is over-dimensioned for the switching requirements of node 20i

and it defines, in case of failure, some interconnections which are not operatively used. For example, while the first receiving transponder $RxT_1(\lambda_x)$ is connected to the second receiver Rx_2 under normal operative conditions, no connection is needed for the first receiving transponder $RxT_1(\lambda_x)$ in case of failure on the external ring 2 on the right-hand side of node 20i (since no signal is received from this side). Taking into consideration this over-dimensioning of the switch unit functionality, it is possible to use, in place of the 2x2 switch type unit, other unit architectures which allow to optimize the number of interconnections in relation to the functional requirements. The interconnection requirements in node 20i under both normal and failure conditions (i.e. for working and protection) is summarized in the following table:

	Rx_1	Rx_2	$TXT_1(\lambda x)$	$TXT_1(\lambda y)$	$TXT_2(\lambda x)$	$TXT_2(\lambda y)$
Tx_1			W		P	
Tx_2				P		W
$RXT_1(\lambda x)$		W				
$RXT_1(\lambda y)$	P			P		
$RXT_2(\lambda x)$		P			P	
$RXT_2(\lambda y)$	W					

W=Working P=Protection

Figure 4 shows a switch unit 15' including 1x2 and 2x1 optomechanical switches, to be used in place of switch unit 15. Switch unit 15' implements the required interconnection functionality and can be, for example, of the type produced by JDS FITEL, INC., 570 Heston Drive, Nepean, Ontario (CA) or of the type produced by E-TEK DYNAMICS, INC., 1885 Lundy Ave., San Jose, CA (USA). In Figure 4, for reason of clarity, the input connections and the output connections of switch unit 15' are grouped on the left side and, respectively, on the right side of switch unit 15'. In detail, switch unit 15' include:

- a first switch 31 of the 1x2 type, having its input coupled to the first transmitter Tx_1 and its first output coupled to the first transmitting transponder $TxT_1(\lambda_x)$;
- a second switch 32 of the 2x1 type, having its first input coupled to the second output of the first switch 31 and its output coupled to the third transmitting transponder $TxT_2(\lambda_x)$;
- a third switch 33 of the 1x2 type, having its input coupled to the third receiving transponder $RxT_2(\lambda_x)$ and its first output coupled to the second input of the second switch 32;
- a fourth switch 34 of the 2x1 type, having its first input coupled to the second

output of the third switch 33, its second input coupled to the first receiving transponder $RxT_1(\lambda_x)$ and its output coupled to the second receiver Rx_2;

- a fifth switch 35 of the 2x1 type, having its first input coupled to the fourth receiving transponder $RxT_2(\lambda_y)$ and its output coupled to the first receiver Rx_1;
- a sixth switch 36 of the 1x2 type, having its input coupled to the second receiving transponder $RxT_1(\lambda_y)$ and a first output coupled to the second input of the fifth switch 35;
- a seventh switch 37 of the 2x1 type, having its first input coupled to the second output of the sixth switch 36 and its output coupled to the second transmitting transponder $TxT_1(\lambda_y)$; and
- an eighth switch 38 of the 1x2 type, having its input coupled to the second transmitter Tx_2, its first output coupled to the second input of the seventh switch 37 and its second output coupled to the fourth transmitting transponder $TxT_2(\lambda_y)$.

In Figure 4, connections which are operative under normal conditions are shown with a continuous line, while connections which are not used under normal condition are represented with a dashed line.

In a further possible embodiment shown in Figure 5, the switch unit, here indicated with 15", includes a lithium niobate ($LiNbO_3$) integrated switching matrix, in which interconnections among input and outputs reproduce the layout of the switch unit 15' of Figure 4. In particular, switch unit 15" includes four 1x2 switches each comprising:

- an input waveguide,
- a Y-shaped branching waveguide having one input arm connected to input waveguide and having two output arms, and
- a first and a second output waveguides each connected to one of the output arms of the branching waveguide,

and four 2x1 switches each comprising:

- a first and a second input waveguide,
- a Y-shaped branching waveguide having two input arms connected to the input waveguide and one output arm, and
- a first output waveguide connected to the output arm of the branching waveguide.

Switch unit 15" also includes electrodes (not shown) formed on the surface of substrate in correspondence of the Y-shaped branching waveguides and adapted to produce the switching action between the two arms of the Y.

In detail, switch unit 15" includes:

- a first switch 41 (1x2) having its input waveguide coupled to the first transmitter

Tx_1 and its first output waveguide coupled to the first transmitting transponder $TxT_1(\lambda_x)$;

- a second switch 42 (2x1) having its first input waveguide coupled to the second output waveguide of the first switch 41 and its output waveguide coupled to the third transmitting transponder $TxT_2(\lambda_x)$;
- a third switch 43 (1x2) having its input waveguide coupled to the third receiving transponder $RxT_2(\lambda_x)$ and its first output waveguide coupled to the second input waveguide of the second switch 42;
- a fourth switch 44 (2x1) having its first input waveguide coupled to the second output waveguide of the third switch 43, its second input waveguide coupled to the first receiving transponder $RxT_1(\lambda_x)$ and its output waveguide coupled to the second receiver Rx_2;
- a fifth switch 45 (2x1) having its first input waveguide coupled to the fourth receiving transponder $RxT_2(\lambda_y)$ and its output waveguide coupled to the first receiver Rx_1;
- a sixth switch 46 (1x2) having its input waveguide coupled to the second receiving transponder $RxT_1(\lambda_y)$ and its first output waveguide coupled to the second input waveguide of the fifth switch 45;
- a seventh switch 47 (2x1) having a first input waveguide coupled to the second output waveguide of the sixth switch 46 and an output waveguide coupled to the second transmitting transponder $TxT_1(\lambda_y)$; and
- an eighth switch 48 (1x2) having an input waveguide coupled to the second transmitter Tx_2, a first output waveguide coupled to the second input waveguide of the seventh switch 47 and a second output waveguide coupled to the fourth transmitting transponder $TxT_2(\lambda_y)$.

In Figure 5, connections which are operative under normal conditions are shown with a continuous line, while connections which are not used under normal condition are represented with a dashed line.

The use of an integrated switching matrix offers several advantages over a discrete components switching matrix. In particular:

- opto-mechanical switch units 15 and 15' are more cumbersome than the integrated switch unit 15"; for example, a typical 2x2 opto-mechanical switch may occupy a surface of about 48x18 mm^2, and four switches are needed to form the switch unit 15, while the integrated switch unit 15" may occupy an area of about 4x65 mm^2;
- integrated switch unit 15" has response times lower than opto-mechanical switch

units 15 and 15'; in fact, integrated switch unit 15" allows response times of about 1 ms, while opto-mechanical switch units 15 and 15' have typical response times of about 5-10 ms;

- the use of a single integrated device in place of four 2x2 switches or eight 1x2 and 2x1 switches allows to simplify the piloting electronic circuit;
- integrated switch unit 15' is cheaper than opto-mechanical switch units 15 and 15'.

Alternatively to the optomechanical switch units 15 and 15' and to the lithium niobate integrated switch unit 15", other types of optical switch units may be used, including either a discrete components switching matrix or an integrated switching matrix, for example including thermo-optical switches, magneto-optical switches, liquid crystal switches, SOA (Semiconductor Optical Amplifier) switches, electro-optical switches and micro-mechanical switches (MEMS).

The node structure previously described is adapted to manage two working links on the same logical ring. Anyway, if the client traffic pattern requires only one working link to be terminated at a generic node, this node may be sub-equipped. This situation is depicted in Figure 6, where a generic one-link node 20j adapted to manage a single working link in its left-hand side is shown under normal operative conditions.

Node 20j differs from the node 20i of Figure 3 in that the second transmitter Tx_2, the second receiver Rx_2, the first receiving transponder $RxT_1(\lambda_x)$ and the fourth transmitting transponder $TxT_2(\lambda_y)$ of node 20i are absent, and in that it includes a switch unit 115 which does not comprise the third and the fourth switch 24, 25 of switch unit 15. Therefore, differently from the architecture of Figure 3, the third receiving transponder $RxT_2(\lambda_x)$ is directly coupled to the second input 22b of the first switch 22 and the second output 23d of the second switch 23 is directly coupled to the second transmitting transponder $TxT_1(\lambda_y)$. The single working link managed by node 20j includes signals sent by node 20j to another node at the working wavelength $\lambda_{x,w}$ on the external ring 2 and signals received by node 20j from the other node at the working wavelength $\lambda_{y,w}$ on the internal ring 3. Protection wavelengths $\lambda_{x,p}$ and $\lambda_{y,p}$ are managed in the same way as described before for the two-link node.

Figure 7 shows an alternative switch unit 115' for a one-link node to be used in place of switch unit 115. Switch unit 115' includes 1x2 and 2x1 optomechanical switches of the same type as those of switch unit 15' and implements the interconnection functionality required for node 20j, omitting the unused

interconnections. For sake of clarity, input connections and output connections of switch unit 115' are grouped on the left side and, respectively, on the right side of switch unit 115'.

Switch unit 115' includes a first switch 131 (1x2), a second switch 132 (2x1), a third switch 135 (2x1) and a fourth switch 136 (1x2) respectively equivalent to switches 31, 32, 35 and 36 of switch unit 15' (Figure 4) and differs from switch unit 15' in that switches 33, 34, 37 and 38 of switch unit 15' are absent.

In detail, switch unit 115' include:

- a first switch 131 of the 1x2 type, having its input coupled to the first transmitter Tx_1 and its first output coupled to the first transmitting transponder $TxT_1(\lambda_x)$;
- a second switch 132 of the 2x1 type, having its first input coupled to the second output of the first switch 131, its second input coupled to the third receiving transponder $RxT_2(\lambda_x)$ and its output coupled to the third transmitting transponder $TxT_2(\lambda_x)$;
- a third switch 135 of the 2x1 type, having its first input coupled to the fourth receiving transponder $RxT_2(\lambda_y)$ and its output coupled to the first receiver Rx_1; and
- a fourth switch 136 of the 1x2 type, having its input coupled to the second receiving transponder $RxT_1(\lambda_y)$, a first output coupled to the second input of the third switch 135 and a second output coupled to the second transmitting transponder $TxT_1(\lambda_y)$.

In Figure 7, connections which are operative under normal conditions are shown with a continuous line, while connections which are not used under normal condition are represented with a dashed line.

Figure 8 shows an integrated optics switch unit 115" having the same switching architecture of switch unit 115' of Figure 7, but realized using the same technology of switch unit 15" of Figure 5, i.e. lithium niobate ($LiNbO_3$) integrated circuit technology. Switch unit 115" includes a first switch 141 (1x2), a second switch 142 (2x1), a third switch 145 (2x1) and a fourth switch 146 (1x2) performing the same signal routing as the corresponding switches of switch unit 115' (figure 7).

Alternatively, switch units 115, 115' and 115" may include switches selectable in the set comprising thermo-optical switches, magneto-optical switches, liquid crystal switches, SOA (Semiconductor Optical Amplifier) switches, electro-optical switches and micro-mechanical switches (MEMS).

Network 1 operates as follows.

When a link between a first and a second node of the network 1 has to be

established, a generic pair of first and second wavelengths λ_x, λ_y is chosen within the wavelength band. A working link is then set up between the two nodes by connecting the first transmitter Tx_1 of the first node to the second receiver Rx_2 of the second node using the first wavelength λ_x on the external ring 2, and by connecting the second transmitter Tx_2 of the second node to the first receiver Rx_1 of the first node using the second wavelength λ_y on the internal ring 3, on a same working arc path. As previously described, other working links may be set up in the protection path of the two considered nodes, provided that the working path used by each working link is non-overlapping with other working paths used by other working links using the same wavelengths. In the case here considered, the second wavelength λ_y on the external ring 2 and the first wavelength λ_x on the internal ring 3 are not used under normal operative conditions, and are reserved for optical protection (i.e. are reserved for use in case of failure).

Each working link is under control of the two nodes at the end of the link itself. This means that, for a working link operating at working wavelengths $\lambda_{x,w}$, $\lambda_{y,w}$, the two nodes at the end of this link must provide the add/drop functions on working wavelengths $\lambda_{x,w}$ and $\lambda_{y,w}$ to/from the set of transmission wavelengths λ_1, ..., λ_N. Moreover, all the required monitoring functions on the transmitted signals (e.g. optical power level, channel identifier, BER performance, etc.) have to be carried out at these terminating nodes. It has to be noted that the nodes not involved in communications on working wavelengths $\lambda_{x,w}$ and $\lambda_{y,w}$ do not provide any function on them, and these wavelengths are directly bypassed. Each node at the end of a working link using wavelengths $\lambda_{x,w}$ and $\lambda_{y,w}$ must also have the control on the protection wavelengths $\lambda_{x,p}$ and $\lambda_{y,p}$, being these wavelengths shared for protection among all the working links of the corresponding logical ring. The other nodes (i.e. the nodes external this logical ring) are not required to perform any operation on $\lambda_{x,p}$ and $\lambda_{y,p}$, and these wavelengths are simply bypassed in these nodes. As a general rule, the nodes not included in a logical ring (i.e. not terminating a generic working link on this logical ring) can be completely transparent to the wavelengths associated to the logical ring.

In the example of Figure 2, the working link between node 20c and node 20f operating on working wavelengths $\lambda_{x,w}$ and $\lambda_{y,w}$ is under control of these two nodes, and the working link between node 20d and 20e operating on the same wavelengths is under control of these two last nodes. Each of the nodes 20c, 20d, 20e and 20f has also the control on the protection wavelengths $\lambda_{x,p}$, $\lambda_{y,p}$ associated to the

corresponding logical ring, in order to have access to the shared protection resource.

Nodes 20a and 20b cannot be part of the logical ring operating at working wavelengths $\lambda_{x,w}$, $\lambda_{y,w}$ and may define termination nodes of working links at wavelengths different from $\lambda_{x,w}$, $\lambda_{y,w}$. Therefore, nodes 20a and 20b do not perform any action on working wavelengths $\lambda_{x,w}$, $\lambda_{y,w}$ and protection wavelengths $\lambda_{x,p}$, $\lambda_{y,p}$, even if they may be required to provide optical amplification on the set of transmission wavelengths $\lambda_1, \ldots, \lambda_N$. Furthermore, each node may be required to provide functions like regeneration or monitoring on the bypassed wavelengths, in order to allow a constant performance control of the set of transmission wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_N$ over the entire ring network. Indeed, under failure conditions, these nodes have not to provide any reconfiguration action on the channels carried by the bypassed wavelengths.

With reference to Figure 3, the signal flow inside the generic node 20i, under normal operative conditions, is as follows.

In reception, the first and the second OADM 4, 5 drop the wavelengths of the logical rings to be managed. All the other wavelengths may be directly bypassed to the node output without any processing. In greater detail, the first OADM 4 drops from the set of transmission wavelengths $\lambda_1, \ldots, \lambda_N$ on the external ring 2 both the working and protection wavelengths $\lambda_{x,w}$ and $\lambda_{y,p}$ (and possibly working and protection wavelengths of other logical rings to be managed), while the second OADM 5 drops from the set of transmission wavelengths $\lambda_1, \ldots, \lambda_N$ on the internal ring 3 both the working and protection wavelengths $\lambda_{y,w}$ and $\lambda_{x,p}$ (and possibly working and protection wavelengths of other logical rings to be managed). Wavelengths $\lambda_{x,w}$, $\lambda_{y,p}$, $\lambda_{y,w}$ and $\lambda_{x,p}$ are sent directly to the respective receiving transponders $RxT_1(\lambda_x)$, $RxT_1(\lambda_y)$, $RXT_2(\lambda_y)$ and $RXT_2(\lambda_x)$, where, after conversion in electric format, information related to the link (link signalling) is extracted and sent to the CPU 16 for processing. After processing, wavelengths $\lambda_{x,w}$, $\lambda_{y,p}$, $\lambda_{y,w}$ and $\lambda_{x,p}$ are newly converted in optical format.

The first working wavelength $\lambda_{y,w}$ is then routed through switch unit 15 to the first receiver Rx_1 and the second working wavelength $\lambda_{x,w}$ is routed through switch unit 15 to the second receiver Rx_2. The first and the second protection wavelengths $\lambda_{x,p}$ and $\lambda_{y,p}$ are by-passed through switch unit 15 to the third transmitting transponder $TxT_2(\lambda_x)$ and, respectively, to the second transmitting transponder $TxT_1(\lambda_y)$, from where they are fed to the internal ring 3 and, respectively, to the external ring 2 by the second OADM 5 and, respectively, the first OADM 4. Signalling information carried by the protection wavelengths is left unchanged since no protection is

required at the moment on the two working channels.

Signals generated by the first transmitter Tx_1 are routed through switch unit 15 to the first tranmitting transponder $TxT_1(\lambda_x)$ for transmission on the first working wavelength $\lambda_{x,w}$, and signals generated by the second transmitter Tx_2 are routed through switch unit 15 to the fourth transmitting transponder $TxT_2(\lambda_y)$ for transmission on the second working wavelength $\lambda_{y,w}$. In the first and the fourth transmitting transponder $TxT_1(\lambda_x)$, $TxT_2(\lambda_y)$, appropriate information (link signalling, channel identifier) generated by CPU 16 is added (for example by using bytes k1 and k2 as recommended in ITU-T standard) to signals on the first working wavelength $\lambda_{x,w}$ and, respectively, on the second working wavelength $\lambda_{y,w}$. These wavelengths are then sent respectively to the external and internal rings 2, 3 by OADMs 4, 5.

Identical operations are performed in each receiving/transmitting module included in node 20i, for corresponding pairs of wavelengths that have to be managed by this node.

When a failure occurs, reconfiguration takes place in all those, and only those, logical rings including at least a working link whose transmission is affected by the failure. It is intended that the failure can be everything affecting the transmission between two nodes, therefore not only a fiber cut but also a failure in a node device such as a OADM or a transponder. Reconfiguration in a logical ring is performed independently from reconfiguration in the other logical rings. In particular, for each working link affected by the failure, reconfiguration takes place only at the pair of nodes terminating the link, while the nodes interposed between these terminating nodes do not perform any action to restore the failed link.

As a consequence of a failure on the generic working link operating at the working wavelengths $\lambda_{x,w}$, $\lambda_{y,w}$, the two nodes terminating the working link detect the failure condition (in the way hereinbelow described) and run the reconfiguration process by switching the transmission on the respective protection arc path using the protection wavelengths $\lambda_{x,p}$, $\lambda_{y,p}$. In practice, signals previously transmitted at the first working wavelength $\lambda_{x,w}$ on the external ring 2 are switched at the first protection wavelength $\lambda_{x,p}$ on the internal ring 3, while signals previously transmitted at the second working wavelength $\lambda_{y,w}$ on the internal ring 3 are switched at the second protection wavelength $\lambda_{y,p}$ on the external ring 2.

The working link between the two nodes is consequently re-routed on the respective protection path by using the protection wavelengths $\lambda_{x,p}$, $\lambda_{y,p}$, if necessary through nodes which are terminating other working links on the same logical ring.

These last nodes do not have to perform any action as a consequence of the reconfiguration process performed by the nodes terminating the working link affected by the failure, but must be aware of the presence of a signal carried by the protection wavelengths in order to know that the protection resource has been taken by another working link of the same logical ring. Therefore, as a consequence of the protection operations performed on the failed working link, all the other working links of the same logical ring become unprotected. This situation persist until the failure has been repaired and the transmission previously switched on the protection path has been restored on the original working link. Moreover, nodes which terminate working links sharing the same protection resource of the failed one (i.e. the working links of the same logical ring) must have the protection mechanism inhibited until normal conditions are restored.

Figure 9 depicts a situation in which a failure occurs in the ring network of Figure 2 between nodes 20a and 20b. According to the above, nodes 20a and 20b do not perform any action in response to the failure because, in the particular condition disclosed, they are not terminating nodes of a working link affected by the failure.

The hereinbelow described sequence of operations for the failure detection and signalling performed by nodes 20c and 20f is to be considered only as an example. Different sequence of operations may alternatively be used, without depart from the scope of the present invention, all leading to a transitory condition at the end of which nodes 20c and 20f are both reconfigured.

Supposing that the failure affects only the transmission from node 20f to node 20c (along the internal ring 3), while the opposite transmission (along the external ring 2) is still operative, node 20c detects the absence of signals or a signal quality degradation (corresponding, for example, to a BER over a predetermined threshold) at the second working wavelength $\lambda_{y,w}$ on the fourth receiving transponder $RxT_2(\lambda_y)$ and, consequently, its CPU 16 operates a reconfiguration of its switch unit 15 (as hereinbelow described with reference to Figure 10) in order to switch the transmission (in the manner described below) on the protection path. Before reconfiguration takes place, node 20c sends node 20f a failure message preferably along both the external ring 2 (in the counter-clockwise direction) and the internal ring 3 (in the clockwise direction) and preferably by using the protection wavelengths $\lambda_{y,p}$ and $\lambda_{y,p}$, to inform node 20f of the new situation.

In the preferred case of the bidirectional message transmission, node 20f receives the message from both the external ring 2 and the internal ring 3 (for

example at the protection wavelengths $\lambda_{x,p}$ and $\lambda_{x,p}$) and reacts by performing the reconfiguration of its switch unit 15 (as shown in Figure 13), consequently switching the transmission on the respective protection path.

On the other hand, if the failure affects only the transmission from node 20c to node 20f (along the external ring 2), a similar sequence of operations is performed starting from node 20f.

Alternatively, if both the transmission directions are affected by the failure, the first one between nodes 20c and 20f becoming aware of the absence of signals or of a signal quality degradation sends the other node the failure message (preferably along both the external ring 2 and the internal ring 3 and preferably by using the protection wavelengths $\lambda_{y,p}$ and $\lambda_{y,p}$) and subsequently operates a reconfiguration of its switch unit 15. The other node realizes the presence of a failure in the considered link either as a consequence of the detection of the absence of signals or of a signal quality degradation, or as a consequence of the reception of the failure message from the first node (and only from one direction, in the preferred case of the bidirectional message transmission) and, in its turn, sends a failure message to the first node and operates a reconfiguration of its switch unit 15.

At the end of the above transitory condition, signals transmitted between nodes 20c and 20f are carried on the respective protection path. Nodes 20d and 20e, which, in the example of Figure 2, are the termination nodes of another working link in the same logical ring, are informed of the new situation by checking the status of the channel carried by the protection wavelengths bypassed (i.e. by reading the failure message), and they consequently inhibit their protection mechanism.

When the failure has been repaired, the normal condition can be restored on each affected logical ring by resetting the switching layouts at the terminating nodes of the failed working links so as to re-route such links on their original working path. On the generic logical ring, all the link terminating nodes not previously affected by the failure are informed of the release of the shared protection capacity by checking the status of the channel carried by the protection wavelengths (which are now unused). As a consequence, these link terminating nodes re-enable their protection mechanism.

Figure 10 depicts the situation in which a failure occurs on a working link defined by the generic node 20i (together with a further node not shown), in particular a failure on the left-hand side of node 20i. Node 20i is informed of the failure condition by detecting, at the fourth receiving transponder $RxT_2(\lambda_y)$, the absence of signals, or a signal quality degradation (like a BER over a predetermined threshold),

or the reception of a failure message (as previously described). CPU 16 consequently generates an appropriate failure message to be sent to the other terminating node of the working link, preferably along both the external ring 2 and the internal ring 3. CPU 16 preferably feeds this failure message to the second transmitting transponder $TxT_1(\lambda_y)$ for transmission at the second protection wavelength $\lambda_{y,p}$ and to the third transmitting transponder $TxT_2(\lambda_x)$ for transmission at the first protection wavelengths $\lambda_{x,p}$. CPU 16 subsequently operates the reconfiguration of switch unit 15, by reconfiguring switches 22 and 23 from the bypass status to the switched status in order to bypass the failed working path and re-route the transmission towards the other node of the failed working link on the respective protection path.

In the new node configuration, the first transmitter Tx_1 is connected to the third transmitting transponder $TxT_2(\lambda_x)$ and the corresponding signals are then sent on the internal ring 3 in clockwise direction, while the first receiver Rx_1 is connected to the second receiving transponder $RxT_1(\lambda_y)$ and the signals are then received from the external ring 2 in counter-clockwise direction. If the considered node includes a switch unit 15' (1x2 and 2x1 switches) or a switch unit 15" (integrated optics) in place of switch unit 15 (2x2 switches), the reconfigured status of the corresponding switch unit is as shown in Figure 11 and, respectively, in Figure 12.

The node at the other end of the affected link performs the same operations, after receiving a failure message from the other node, or after detecting the absence of signals or a signal quality degradation at its first receiving transponder $RxT_1(\lambda_x)$. The working link between the two nodes is consequently re-routed on the protection path associated to the working link. Both the reconfigured nodes have also to update the signalling information (generated by the respective CPUs and added to the transmitted signals in the respective transmitting transponders TxTs) carried by the protection wavelengths $\lambda_{x,p}$, $\lambda_{y,p}$ in order to inform all the other nodes on the same logical ring that the shared resource is at present used by the two considered nodes.

When the failure has been repaired, both the nodes at the end of the affected link can be restored to the normal operative condition of Figure 3, thus releasing the shared protection resource.

In nodes including more than one receiving/transmitting module 6, the described protection mechanism operates independently for each module 6.

Figures 13-15 depicts the situation in which a failure occurs on the right-hand side of the generic node 20i. The reconfiguration process is very similar to the one referred to the left-hand side failure and is not here described.

It is intended that, without depart from the scope of the present invention, the architecture of the nodes may me arranged so that, in the absence of failures, protection wavelengths $\lambda_{x,p}$ on the internal ring 3 and $\lambda_{y,p}$ on the external ring 2 may be used to transport low-priority in the same direction as the other wavelengths on the same ring.

CLAIMS

1. Autoprotected optical communication ring network, including a first and a second optical carrier (2, 3) having opposite transmission directions and a plurality of optically reconfigurable nodes (20a-20f) optically connected along the first and the second optical carrier (2, 3) and adapted to communicate in pairs by means of respective links susceptible of failure, the ring network having a normal operative condition in which the nodes of each pair are optically configured so as to exchange optical signals on a respective working arc path at a respective first wavelength (λ_x) on the first carrier (2) and at a respective second wavelength (λ_y) different from said first wavelength (λ_x) on the second carrier (3), said respective working path having a complementary arc path defining a respective protection arc path in which the first wavelength (λ_x) on the first carrier (2) and the second wavelength (λ_y) on the second carrier (3) can be used for further links, and the first wavelength (λ_x) on the second carrier (3) and the second wavelength (λ_y) on the first carrier (2) are reserved for protection, characterized in that the ring network has a failure operative condition in which the nodes terminating a failured link are optically reconfigured so as to exchange optical signals on the respective protection arc path at the respective second wavelength (λ_y) on the first carrier (2) and at the respective first wavelength (λ_x) on the second carrier (3).

2. Ring network according to claim 1, wherein each of said plurality of reconfigurable nodes (20a-20f) is adapted to manage a predetermined subset of wavelengths within a set of transmission wavelengths (λ_1, λ_2 .., λ_N) and includes a first and a second optical add/drop multiplexer (4, 5) serially connected to said first and, respectively, second carrier (2, 3) to feed/extract said subset of wavelengths to/from said first and, respectively, second carrier (2, 3), and to pass-through the remaining wavelengths of the set of transmission wavelengths (λ_1, λ_2, .., λ_N).

3. Ring network according to claim 1, wherein each of said plurality of reconfigurable nodes (20a-20f) includes at least an optical transmitter (Tx_1), at least an optical receiver (Rx_1) and a reconfigurable optical switch unit (15; 15'; 15"; 115'; 115") selectively coupling said optical transmitter (Tx_1) and said receiver (Rx_1) to said first and second carriers (2, 3).

4. Ring network according to claim 3, wherein each of said plurality of reconfigurable nodes (20a-20f) includes information insertion devices (TxTs) selectively optically connectable to said at least an optical transmitter (Tx_1) and adapted to insert signalling information into the optical signals and information extraction devices (RxTs) selectively optically connectable to said at least an optical receiver (Rx_1) and adapted to extract signalling information from the optical signals.

5. Ring network according to claim 4, wherein said information insertion devices (TxTs) and said information extraction devices (RxTs) include optical transponders optically coupling said optical switch unit (15; 15'; 15"; 115'; 115") to said first and second carrier (2, 3) and adapted to change the signals wavelengths.

6. Method to autoprotect an optical ring network, said ring network including a first and a second optical carrier having opposite transmission directions and a plurality of nodes optically connected along the first and the second optical carrier and adapted to communicate in pairs in order to define bidirectional links, each pair including a first and a second link termination node adapted to mutually communicate at respective first and second wavelengths, the method including:
   - exchanging signals between the first and the second link termination node of each pair on a respective working arc path of said ring network by using the respective first wavelength on the first carrier and the respective second wavelength on the second carrier; said respective working path having a complementary arc path defining a respective protection arc path in which the first wavelength on the first carrier and the second wavelength on the second carrier can be used for further links and the first wavelength on the second carrier and the second wavelength on the first carrier are reserved for protection;
   - checking if a failure is present in the ring network producing at least a failured link; and
   - optically reconfiguring, in the presence of a failure, the link terminating nodes of said at least a failured link so that they exchange signals on the respective protection arc path by using the respective first wavelength on the second carrier and the respective first wavelength on the second carrier.

7. Method according to claim 6, wherein each node of said plurality of nodes is adapted to manage a predetermined subset of wavelengths within a set of transmission wavelengths carried by the first and the second carrier, said step of exchanging including optically separating, at each node of said plurality of nodes, each wavelength of the respective subset of wavelengths from the set of transmission wavelengths.

8. Method according to claim 6, wherein the step of checking includes verifying, in each node of said plurality of nodes and for each wavelength of the respective set of wavelengths, if signals are received.

9. Method according to claim 6, wherein said step of checking includes verifying, in each node of said plurality of nodes and for each wavelength of the respective set of wavelengths, if signals are received degraded.

10. Method according to claim 6, wherein said step of checking includes verifying, in each node of said plurality of nodes and for each wavelength of the respective set of wavelengths, if signals include a failure message.

11. Method according to claim 6, further including transmitting a failure message from a first link termination node of a pair to a second link termination node of the same pair if a signal transmitted from the second link termination node to the first link termination node is not received, or is received degraded, by the first link termination node.

12. Method according to claim 6, wherein said step of reconfiguring includes switching optical connections which selectively couple at least an optical transmitter and an optical receiver to said first and second carrier.

13. Reconfigurable node for an autoprotected optical communication ring network, comprising a receiving/transmitting module (6) including:
- an optical transmitter (Tx_1) to generate a signal including information to be transmitted in the network;
- an optical receiver (Rx_1) to receive a signal including information transmitted in the network;

- a first transmitting transponder ($TxT_1(\lambda_x)$) for optically coupling to a first carrier (2) of the network and adapted to modulate a signal at a first wavelength (λ_x);
- a second transmitting transponder ($TxT_1(\lambda_y)$) for optically coupling to the first carrier (2) and adapted to modulate a signal at a second wavelength (λ_y);
- a third transmitting transponder ($TxT_2(\lambda_x)$) for optically coupling to a second carrier (3) of the network and adapted to modulate a signal at the first wavelength (λ_x);
- a first receiving transponder ($RxT_2(\lambda_x)$) for optically coupling to the first carrier (2) and adapted to demodulate a signal having the first wavelength (λ_x);
- a second receiving transponder ($RxT_2(\lambda_y)$) for optically coupling to the first carrier (2) and adapted to demodulate a signal having the second wavelength (λ_y);
- a third receiving transponder ($RxT_1(\lambda_y)$) for optically coupling to the second carrier (3) and adapted to demodulate a signal having the second wavelength (λ_y);
- reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) to selectively connect:
  - the optical transmitter (Tx_1) either to the first transmitting transponder ($TxT_1(\lambda_x)$) or to the third transmitting transponder ($TxT_2(\lambda_x)$);
  - the first receiving transponder ($RxT_2(\lambda_x)$) to the third transmitting transponder ($TxT_2(\lambda_x)$);
  - the second receiving transponder ($RxT_2(\lambda_y)$) to the optical receiver (Rx_1); and
  - the third receiving transponder ($RxT_1(\lambda_y)$) either to the optical receiver (Rx_1) or to the second transmitting transponder ($TxT_1(\lambda_y)$).

14. Reconfigurable node according to claim 13, wherein the receiving/transmitting module (6) further includes:

- a further optical transmitter (Tx_2) to generate a signal including information to be transmitted in the network;
- a further optical receiver (Rx_2) to receive a signal including information transmitted in the network;
- a fourth transmitting transponder ($TxT_2(\lambda_y)$) optically coupled to the second carrier (3) and adapted to modulate a signal at the second wavelength (λ_y); and

- a fourth receiving transponder ($RxT_1(\lambda_x)$) optically coupled to the first carrier (2) and adapted to demodulate a signal having the first wavelength (λ_x);

said reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) selectively connecting:

- the first receiving transponder ($RxT_2(\lambda_x)$) either to the third transmitting transponder ($TxT_2(\lambda_x)$) or to the further receiver (Rx_2);
- the fourth receiving transponder ($RxT_1(\lambda_x)$) to the further receiver (Rx_2); and
- the further optical transmitter (Tx_2) either to the second transmitting transponder ($TxT_1(\lambda_y)$) or to the fourth transmitting transponder ($TxT_2(\lambda_y)$).

15. Reconfigurable node according to claim 13 or 14, characterized in that it is adapted to manage a predetermined set of wavelengths within a set of transmission wavelengths ($\lambda_1, \lambda_2, \ldots, \lambda_N$) including a first and a second optical add/drop multiplexer (4, 5) optically coupling the receiving/transmitting module (6) to said first and, respectively, second carrier (2, 3) to feed/extract said subset of wavelengths to/from said first and, respectively, second carrier (2, 3), and to pass-through the remaining wavelengths of the set of transmission wavelengths ($\lambda_1, \lambda_2, \ldots, \lambda_N$).

16. Reconfigurable node according to claim 13 or 14, wherein the reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) include 2x2 switches.

17. Reconfigurable node according to claim 13 or 14, wherein the reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) include 1x2 and 2x1 switches.

18. Reconfigurable node according to claim 16 or 17, wherein the reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) include discrete switching components.

19. Reconfigurable node according to claim 16 or 17, wherein the reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) include an integrated switching matrix.

20. Reconfigurable node according to claim 18 or 19, wherein the reconfigurable optical connections (22-25; 31-38; 41-48; 131-136; 141-146) include optical switching components selectable in the group including:
    - opto-mechanical switches;
    - thermo-optical switches;
    - magneto-optical switches;
    - liquid crystal switches;
    - semiconductor switches;
    - electro-optical switches;
    - micro-mechanical switches; and
    - lithium niobate integrated circuit switches.

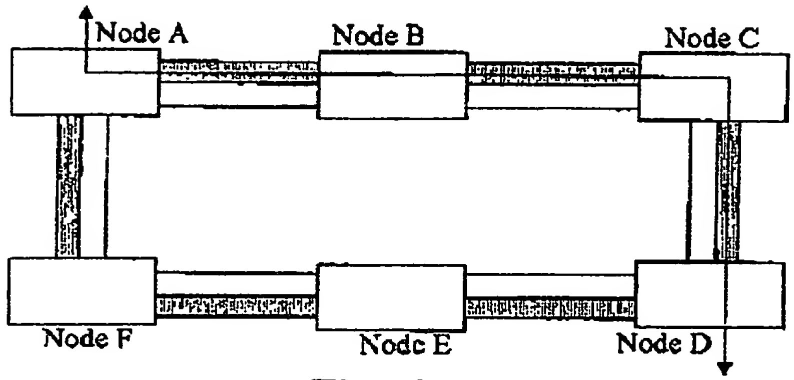


Fig. 1a

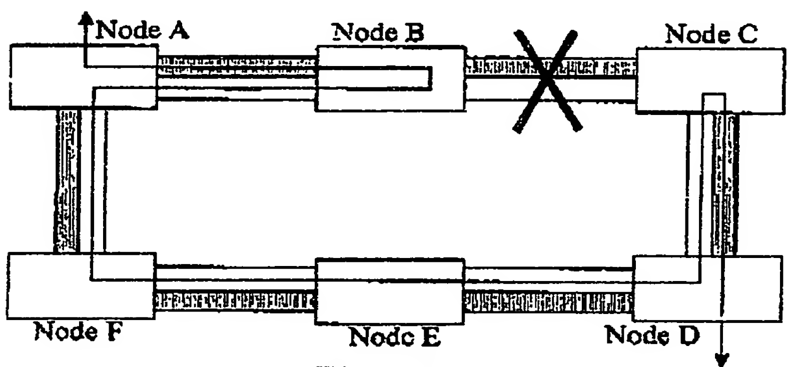


Fig. 1b

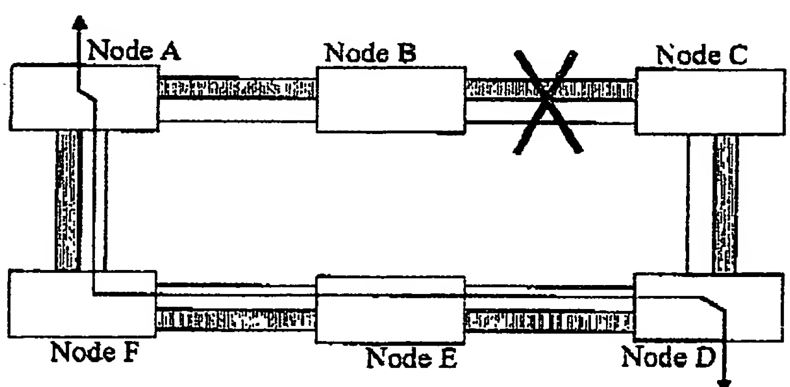
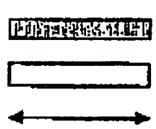


Fig. 1c



2/11

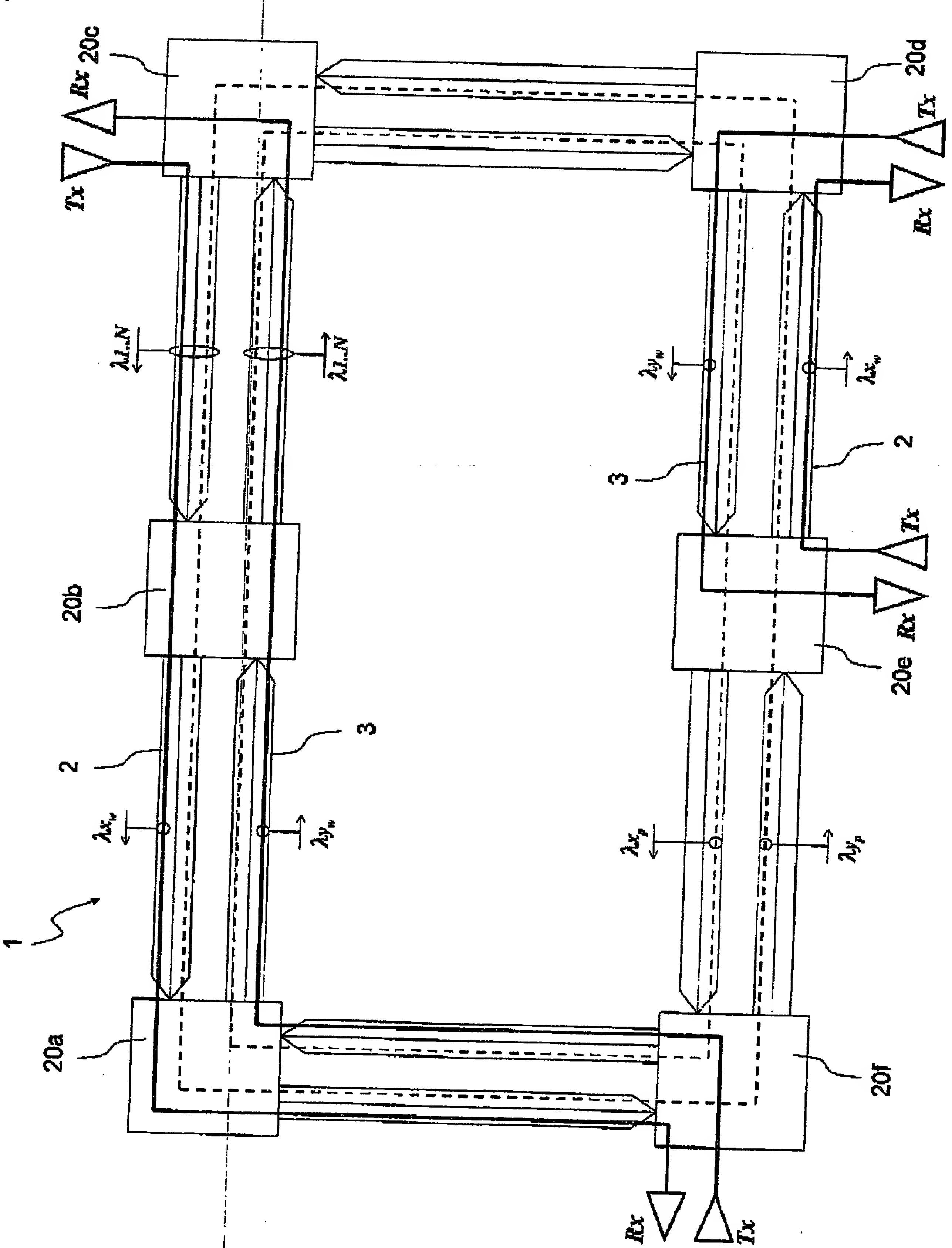


Fig. 2

PC811

3/11

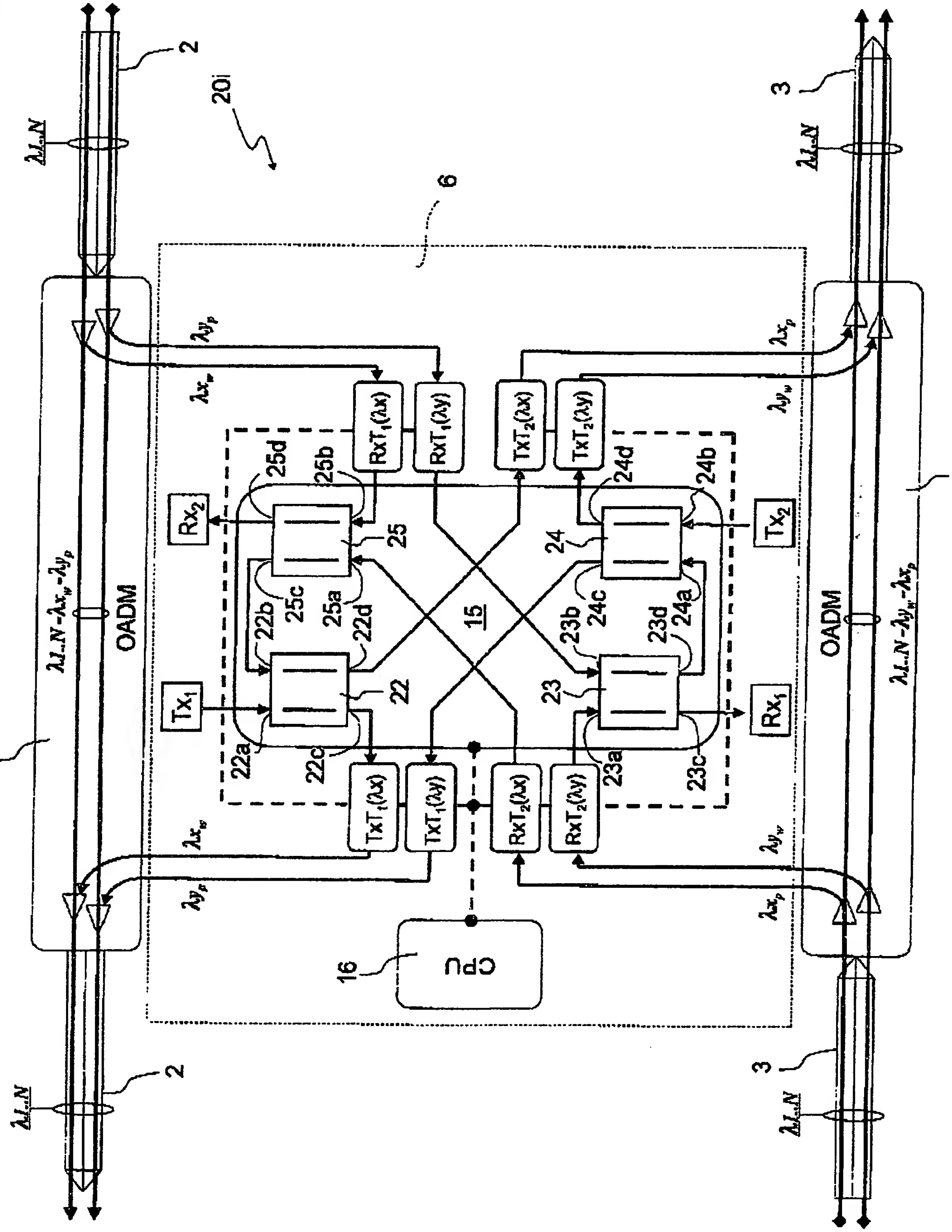


Fig. 3

PC811

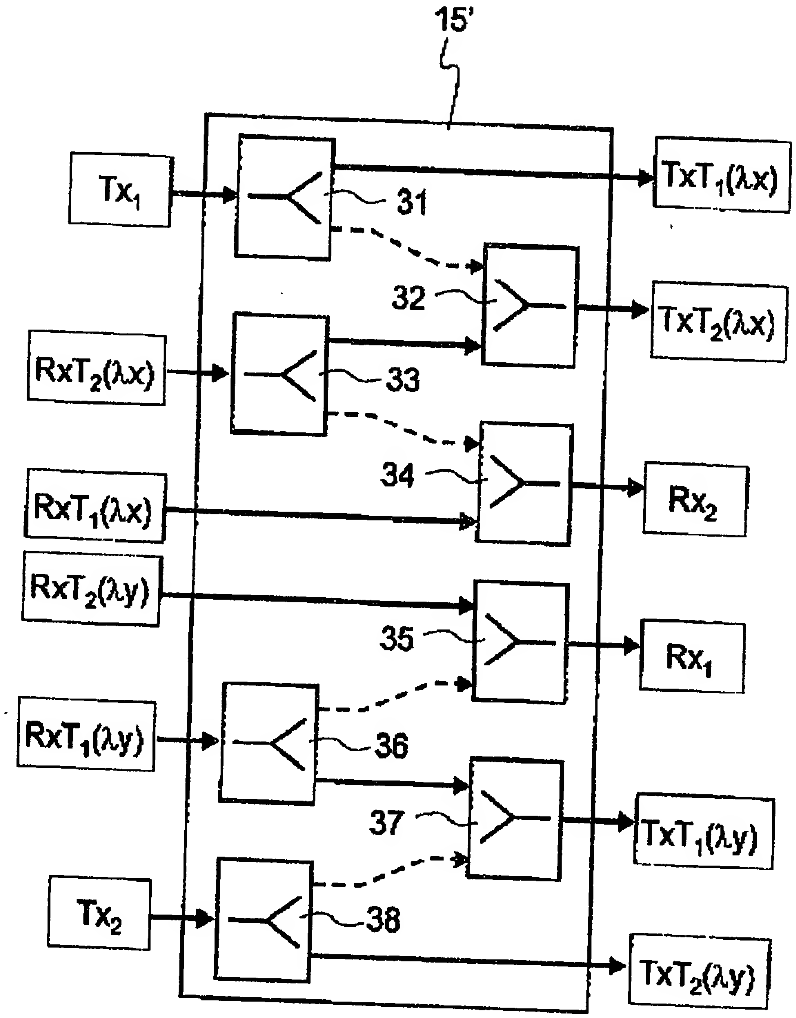

15'
Tx_1
$RxT_2(\lambda x)$
$RxT_1(\lambda x)$
$RxT_2(\lambda y)$
$RxT_1(\lambda y)$
Tx_2
31
32
33
34
35
36
37
38
$TxT_1(\lambda x)$
$TxT_2(\lambda x)$
Rx_2
Rx_1
$TxT_1(\lambda y)$
$TxT_2(\lambda y)$

Fig. 4

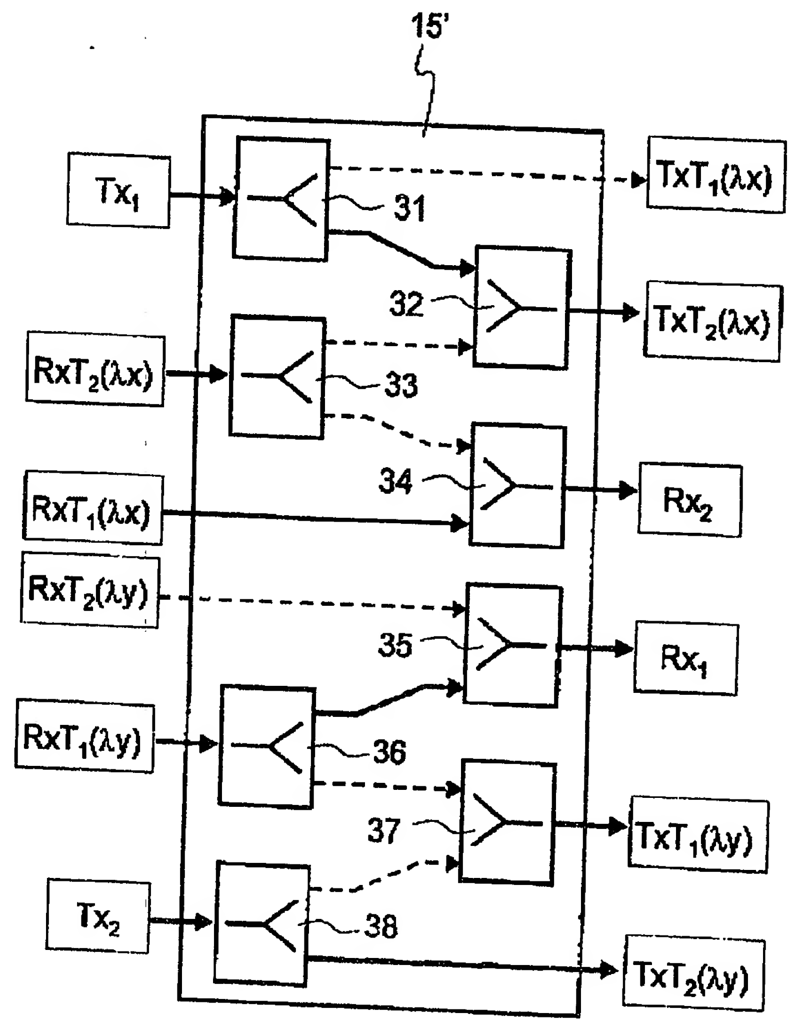

15'
Tx_1
$RxT_2(\lambda x)$
$RxT_1(\lambda x)$
$RxT_2(\lambda y)$
$RxT_1(\lambda y)$
Tx_2
31
32
33
34
35
36
37
38
$TxT_1(\lambda x)$
$TxT_2(\lambda x)$
Rx_2
Rx_1
$TxT_1(\lambda y)$
$TxT_2(\lambda y)$

Fig. 11

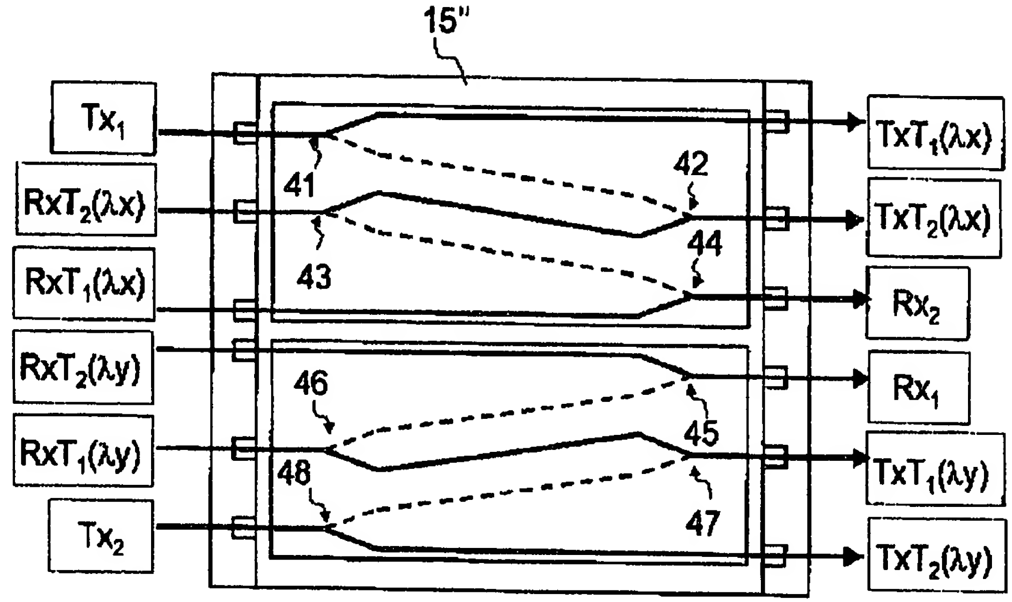

15"
Tx1
RxT2(λx)
RxT1(λx)
RxT2(λy)
RxT1(λy)
Tx2
41
42
43
44
45
46
47
48
TxT1(λx)
TxT2(λx)
Rx2
Rx1
TxT1(λy)
TxT2(λy)

Fig. 5

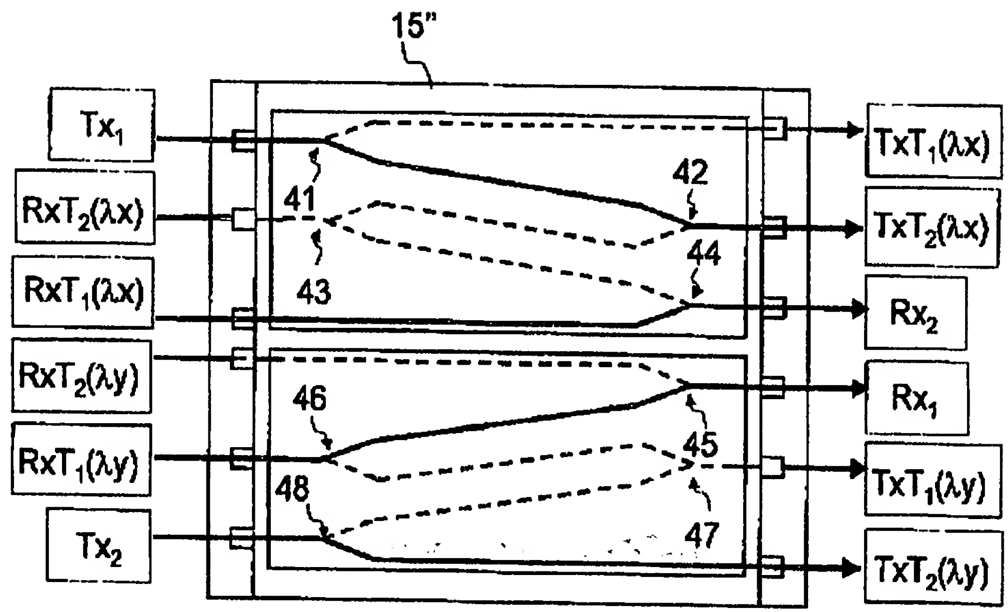

15"
Tx1
RxT2(λx)
RxT1(λx)
RxT2(λy)
RxT1(λy)
Tx2
41
42
43
44
45
46
47
48
TxT1(λx)
TxT2(λx)
Rx2
Rx1
TxT1(λy)
TxT2(λy)

Fig. 12

PC811

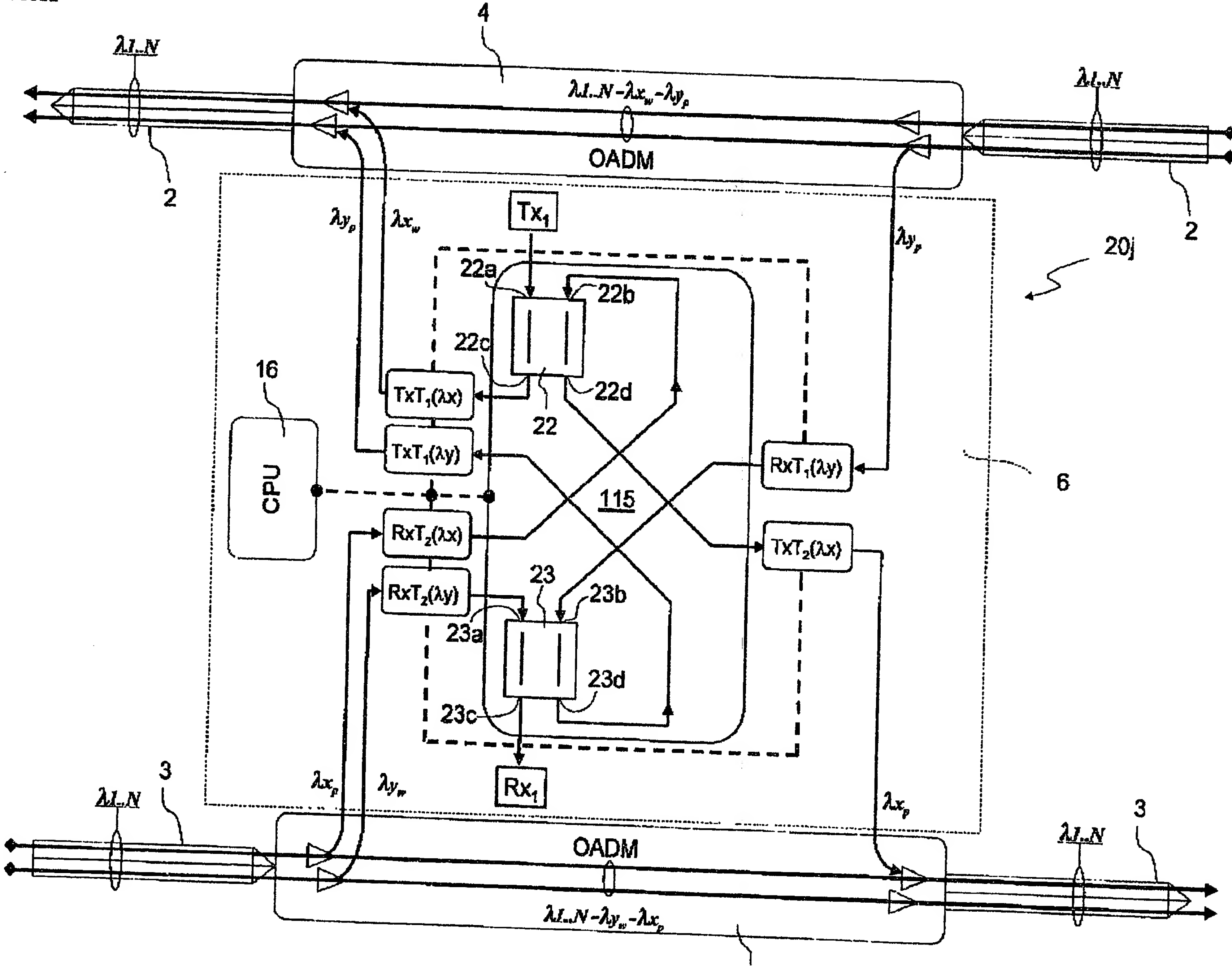

4
2
λ1..N
λ1..N-λxw-λyp
OADM
20j
6
Tx1
22a
22b
22c
22d
22
TxT1(λx)
TxT1(λy)
RxT1(λy)
TxT2(λx)
RxT2(λx)
RxT2(λy)
CPU
16
115
23
23a
23b
23c
23d
Rx1
λyp
λxw
λxp
λyw
3
λ1..N-λyw-λxp
5

Fig. 6

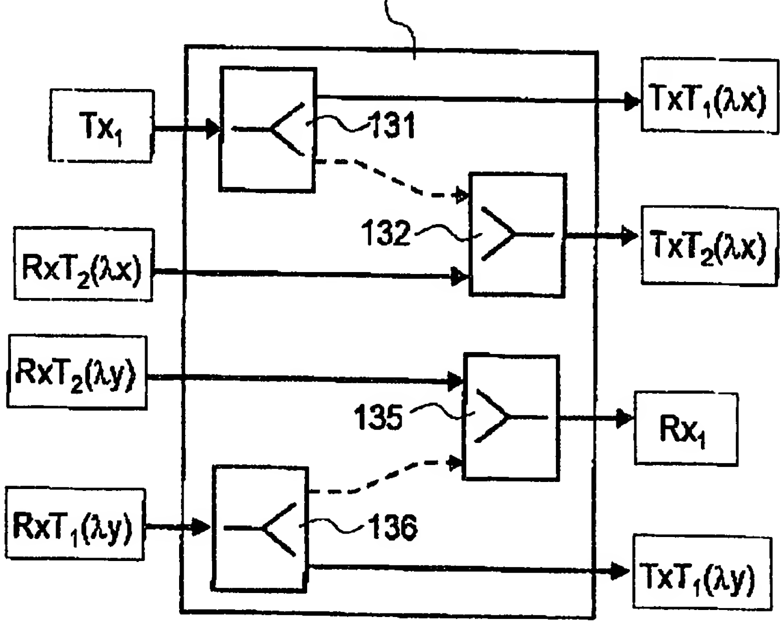

115'
Tx1
RxT2(λx)
RxT2(λy)
RxT1(λy)
131
132
135
136
TxT1(λx)
TxT2(λx)
Rx1
TxT1(λy)

Fig. 7

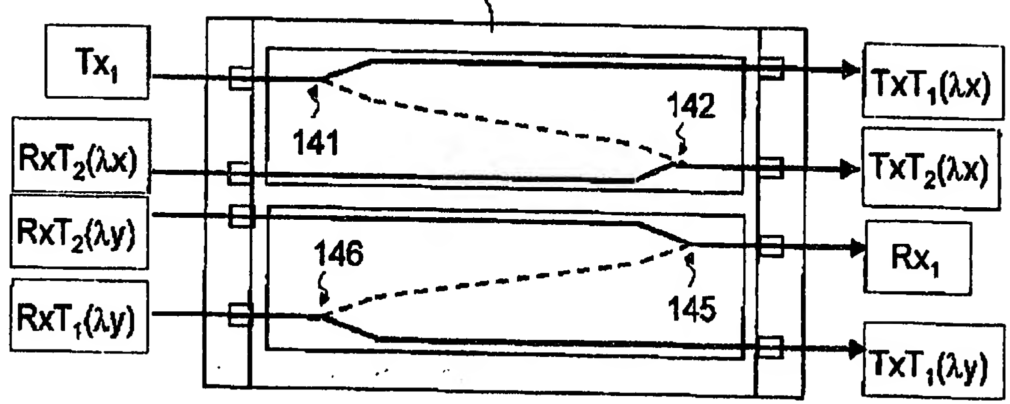

115"
Tx1
RxT2(λx)
RxT2(λy)
RxT1(λy)
141
142
146
145
TxT1(λx)
TxT2(λx)
Rx1
TxT1(λy)

Fig. 8

8/11

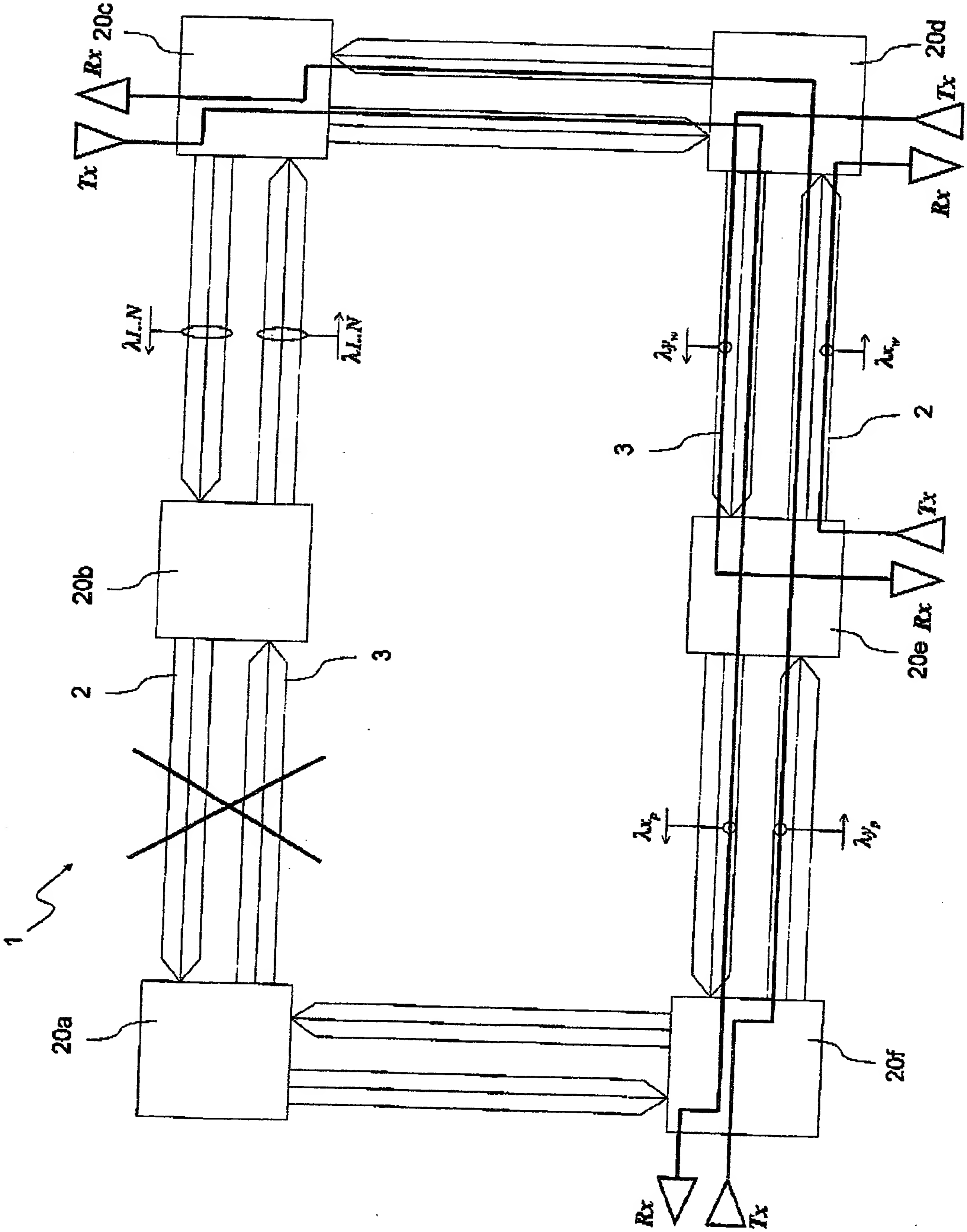


Fig. 9

PC811

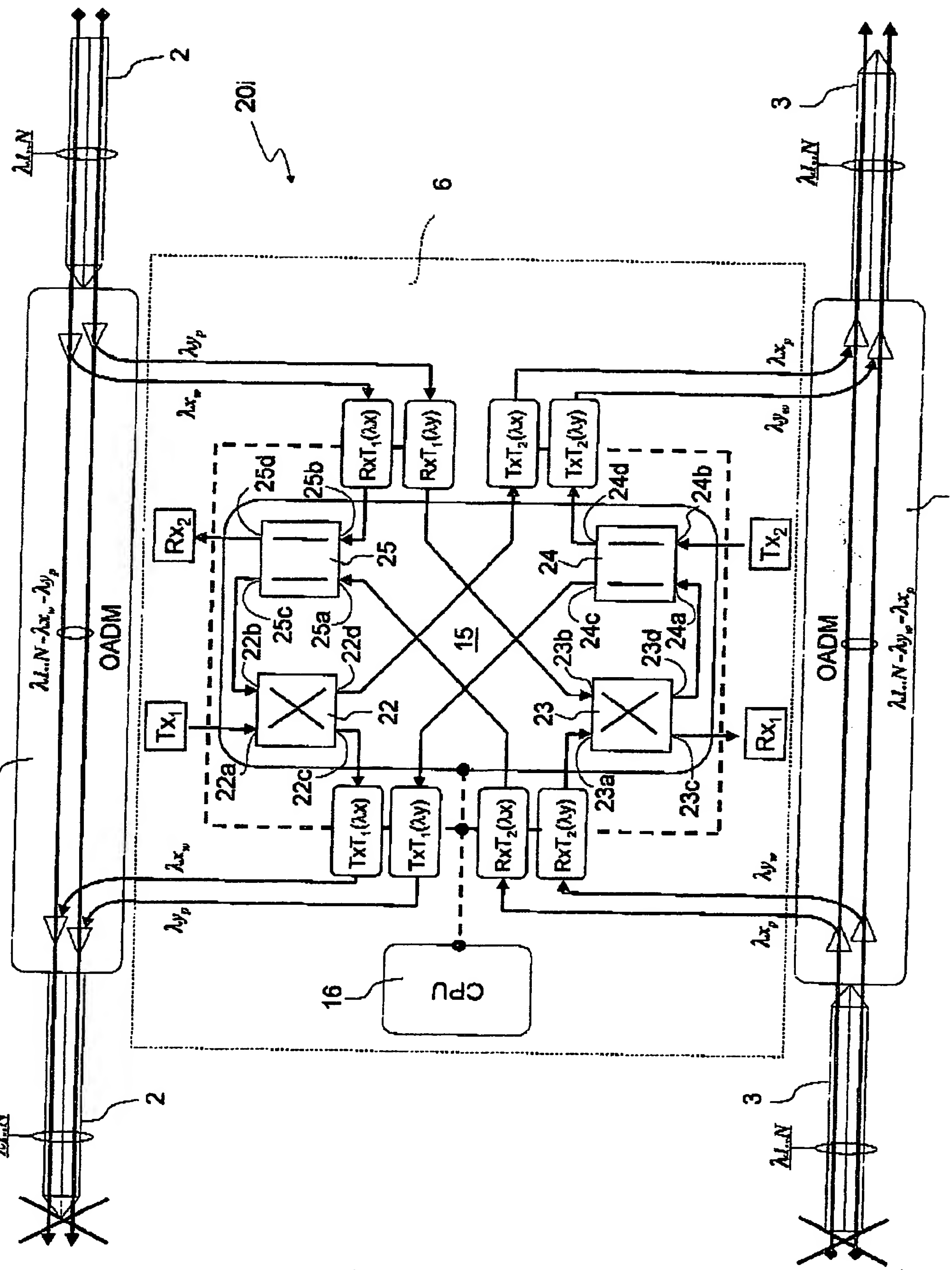

2
20i
6
3
4
5
OADM
OADM
λ1..N
λ1..N-λxw-λyp
λ1..N-λyw-λxp
λxw
λyp
λxp
λyw
RxT1(λx)
RxT1(λy)
TxT2(λx)
TxT2(λy)
TxT1(λx)
TxT1(λy)
RxT2(λx)
RxT2(λy)
Tx1
Tx2
Rx1
Rx2
22
23
24
25
15
22a
22b
22c
22d
23a
23b
23c
23d
24a
24b
24c
24d
25a
25b
25c
25d
CPU
16

Fig. 10

PC811

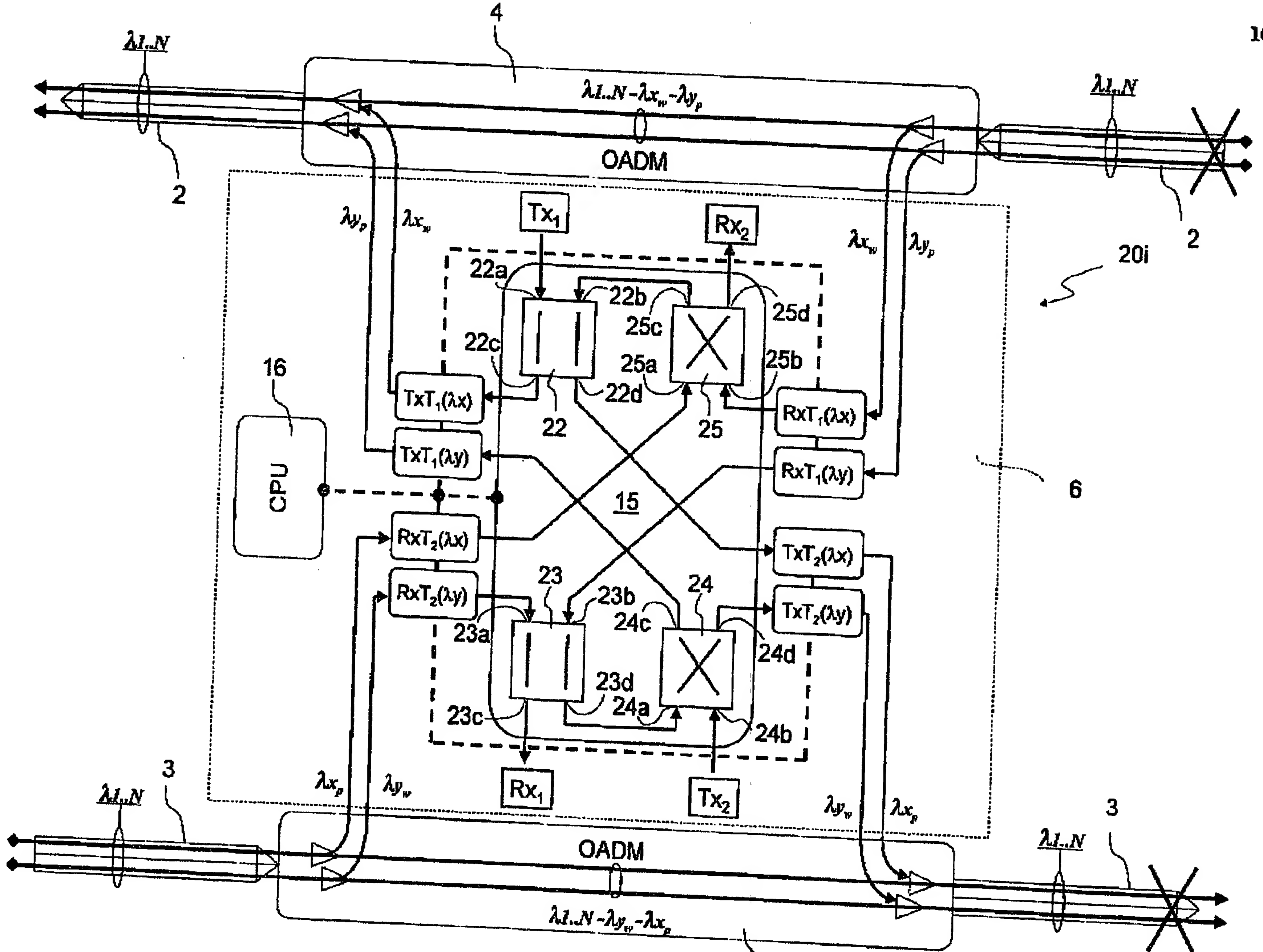

λ1..N
4
λ1..N-λxw-λyp
OADM
2
λyp
λxw
Tx1
Rx2
22a
22b
25c
25d
22c
25a
25b
22d
TxT1(λx)
RxT1(λx)
22
25
16
TxT1(λy)
RxT1(λy)
CPU
15
RxT2(λx)
TxT2(λx)
RxT2(λy)
23
23b
24
TxT2(λy)
23a
24c
24d
23d
24a
23c
24b
Rx1
Tx2
λxp
λyw
3
OADM
λ1..N-λyw-λxp
5
20i
6

Fig. 13

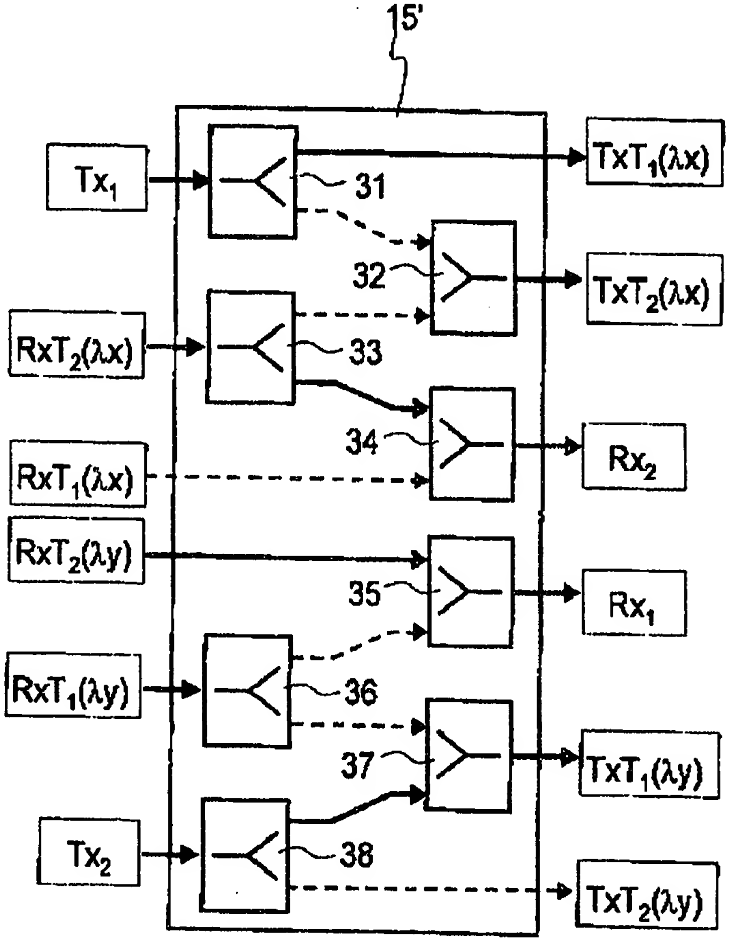

15'
Tx1
RxT2(λx)
RxT1(λx)
RxT2(λy)
RxT1(λy)
Tx2
31
32
33
34
35
36
37
38
TxT1(λx)
TxT2(λx)
Rx2
Rx1
TxT1(λy)
TxT2(λy)

Fig. 14

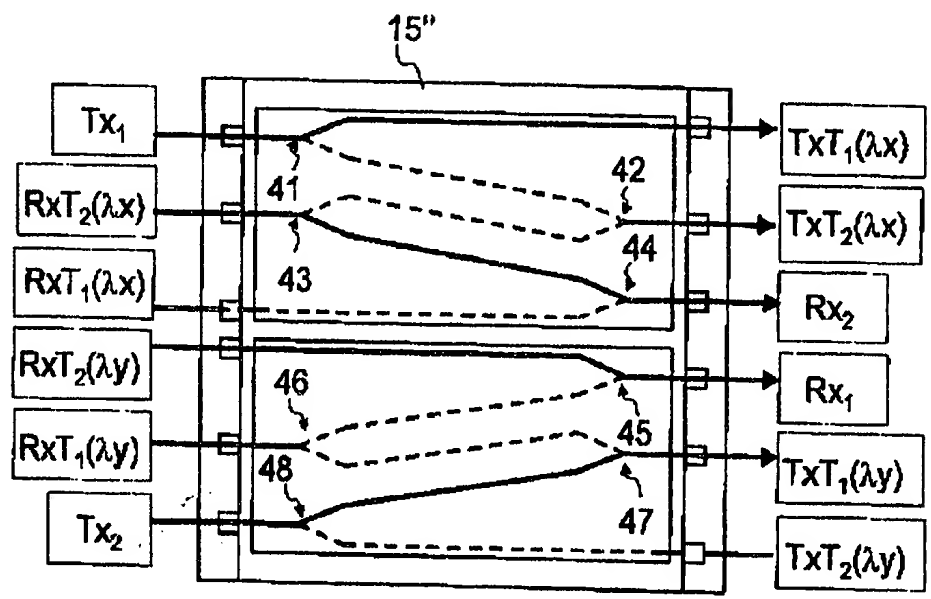

15"
Tx1
RxT2(λx)
RxT1(λx)
RxT2(λy)
RxT1(λy)
Tx2
41
42
43
44
45
46
47
48
TxT1(λx)
TxT2(λx)
Rx2
Rx1
TxT1(λy)
TxT2(λy)

Fig. 15

ABSTRACT

An autoprotected optical communication ring network includes a first and a second optical carrier (2, 3) having opposite transmission directions and a plurality of optically reconfigurable nodes (20a-20f) optically connected along the first and the second optical carrier (2, 3) and adapted to communicate in pairs by means of respective links susceptible of failure, the ring network having a normal operative condition in which the nodes of each pair are optically configured so as to exchange optical signals on a respective working arc path at a respective first wavelength (λ_x) on the first carrier (2) and at a respective second wavelength (λ_y) different from the first wavelength (λ_x) on the second carrier (3), the respective working path having a complementary arc path defining a respective protection arc path in which the first wavelength (λ_x) on the first carrier (2) and the second wavelength (λ_y) on the second carrier (3) can be used for further links and the first wavelength (λ_x) on the second carrier (2) and the second wavelength (λ_y) on the first carrier (3) are reserved for protection, the ring network having also a failure operative condition in which the nodes terminating a failured link are optically reconfigured so as to exchange optical signals on the respective protection arc path at the respective second wavelength (λ_y) on the first carrier (2) and at the respective first wavelength (λ_x) on the second carrier (3).